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TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. XXIV.

JANUARY TO JUNE, 1891.

NEW YORK:

PUBLISHED BY THE SOCIETY.

1891.

Entered according to Act of Congress, by the American Society of Civil Engineers, in the office of the Librarian of Congress at Washington.

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ERRATA.

Page 3, 4th line of paragraph beginning "WIDTH OF BASE," for "sections" read "exceptions."

Page 4, 1st line, for "interest" read "intent."

Page 5, table, strike out the references to maximum and minimum.

Page 5, 3d paragraph from bottom. Precede it by the words "*Thickness of Neck.*—"

Page 5, last paragraph, for "8-degree 18-feet" read "8-degree 18-minutes," and for "13-degree 45-feet" read "13-degree 45 minute."

Page 10, 1st line of 3d paragraph from bottom, for "14 degrees 02 inches" read "14-degrees 02-minutes."

Page 10, 4th line from bottom, insert a period for the comma after "rapidly."

Plate I. The percentages on the sections of A. M. Wellington should read 40, 22½ and 37½, instead of 40, 22 and 38.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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461.

(Vol. XXIV.—January, 1891.)

PROGRESS REPORT OF THE COMMITTEE ON STANDARD RAIL SECTIONS.*

To the President and Members of the American Society of Civil Engineers:

Your Committee on Standard Rail Sections begs leave to submit the following progress report:

The Committee met at the House of the Society, October 1st, eight members being present and four absent (one appointment being vacant); and organized by the choice of G. Bouscaren as Chairman, and A. M. Wellington as Secretary.

After some preliminary discussion it was resolved on motion of Mr. Morison that each member of the Committee be requested to propose a design, or scheme, for a set of sections, and transmit the same to the Secretary of the Committee on or before December 1st, 1890; and that the Secretary be requested to canvass these suggestions and report to the Committee in what respects they agree and disagree. It was also resolved that these sections be prepared according to the individual preference of each member, regardless of any prior recommendations.

In accordance with this resolution ten different sets of designs have been prepared and transmitted to the Secretary, submitted by eleven

* Presented and accepted at the Annual Meeting, January 21st, 1891.

different members, viz.: Messrs. G. Bouscaren, J. Foster Crowell, S. M. Felton, Jr., H. Stanley Goodwin and Samuel Rea, J. D. Hawks, R. W. Hunt, George S. Morison, E. D. T. Myers, Thomas Rodd and A. M. Wellington. V. G. Bogue was appointed on the Committee too late to prepare a set of sections, and no set has been received from Mr. F. M. Wilder, the only remaining member of the Committee.

The last of these sets of sections was not received until just before the meeting; consequently the Committee has not yet been able to take any action upon the report of the Secretary in regard to them. The Secretary's report is subjoined to this report, with engravings of the several sets of sections, and the accompanying memoranda sent in by the members of the Committee.

These sections show a fair degree of agreement, considering that they were designed prior to all attempt at comparison of views. The further steps of the Committee have not yet been determined on.

For the Committee.

G. BOUSCAREN,
Chairman.

REPORT OF THE SECRETARY TO THE COMMITTEE.

To the Committee on Standard Rail Sections:

Agreeably to the vote of instructions passed at the last meeting of the Committee, to the effect that each member of the Committee be requested to send to the Secretary of the Committee a set of sections embodying his own personal preferences or suggestions in regard to a set of Standard Sections, and that the Secretary report to the Committee in what respects they agree and disagree, the Secretary submits the following report:

Ten different complete sets of designs have been received, from eleven different members of the Committee, the only members who have not sent in sections being Messrs. Bogue and Wilder. Full-size drawings of these sections are shown on the accompanying sheet. Messrs. Rea and Goodwin submit a set of sections conjointly. The sections appear to show a remarkable degree of uniformity in their main features. In their several details they stand as follows:

1. The late Committee on the Proper Relation to Each Other of the Sections of Railway Wheels and Rails made the following recommendations: (1) 12-inch top radius; (2) $\frac{1}{4}$-inch corner radius; (3) vertical sides; (4) $\frac{1}{16}$-inch lower corner radius; (5) broad head relatively to depth. In regard to these details, the suggestions of the members of the present Committee stand as follows:

(1) 12-inch top radius. (2) $\frac{1}{4}$-inch corner radius. (3) Vertical sides.	9 sets of sections out of 10 agree with all these recommendations. The set by Messrs. Rea and Goodwin has $\frac{7}{16}$ to $\frac{1}{2}$ inch corner radius and slightly flaring sides, but retains the 12-inch top radius.

(4.) $\frac{1}{16}$ inch lower corner radius. All sections have this except that Messrs. Hunt, Rea and Goodwin make it $\frac{1}{8}$-inch. Bouscaren and Crowell $\frac{3}{32}$, Hawks a sharp corner (being 5 for $\frac{1}{16}$-inch, 5 for a somewhat larger radius, and 1 for a sharp corner).

(5) Broad head relatively to depth.—This recommendation being in-

determinate, the degree of agreement can best be judged from the sections. It appears to be unanimously accepted in principle, except that Mr. Morison sacrifices it to some extent to obtain the same width of head (2½ inches) for all sections from 50 to 100 pounds, inclusive. Messrs. Rea and Goodwin's sections are also a partial exception.

(6) Total Height.

The preferences as to this may be tabulated as follows:

Weight of Section.	Bouscaren.	Crowell.	Felton.	Goodwin and Rea.	Hawks.	Hunt.	Morison	Myers.	Rodd.	Wellington.	Average.
Pounds.											
40	3.50	3.75	3.50	3.50	3.62	3.50	....	3.65	....	3.67	3.58
50	3.87	4.00	4.00	4.00	4.00	4.00	3.95	4.00	4.00	4.00	3.98
60	4.25	4.25	4.00	4.25	4.50	4.25	4.33	4.40	4.25	4.33	4.28
70	4.62	4.62	4.50	4.50	4.75	4.75	4.68	4.73	4.75	4.67	4.66
80	5.00	5.00	5.00	4.75	5.00	5.00	5.00	5.07	5 00	5.00	4.98
90	5.37	5.37	5.50	5.00	5.19	5.50	5.30	5.38	5.25	5.33	5.37
100	5.75	6.00	6.00	5.25	5.50	5.75	5.59	5.68	5.50	5.67	5.47
110	....	....	....	....	....	....	....	....	...	6.00	....

The sections sent in by Messrs. Morison, Myers and Wellington vary in height by some fixed law; all others determine heights arbitrarily. The effort seems to approximate to a uniform variation of ⅓ inch in height for each 10 pounds per yard of difference in weight.

Width of Base.—The Goodwin and Rea set of sections has the base ¼ inch wider than the total height throughout. Otherwise the width of base is the same as the total height throughout the sections, with but two partial sections; Crowell makes the 100-pound section 5½ inch base to 6 inches high; Mr. Wellington stops widening the base at 5 inches with the 80-pound section (to and including which the width and height are alike) and retains a 5-inch base for a 90, 100 and 110-pound section, with heights 5⅓, 5⅔ and 6 inches respectively. This is stated to be done for the reason that rails above 80 pounds demand the use of base-plates, for which a 5-inch base is sufficient, while for such heavy sections it becomes increasingly important to have sections well adapted for rolling.

Mean Distribution of Metal, Average of all Sections.

	Head per cent.	Neck per cent.	Base per cent.	Head Varies Between
Bouscaren	44.5	20.4	35.1	42.7 and 45.3 per cent.
Crowell	40.8	24.0	35.2	38.7 and 41.5 "
Felton	42.6	18.7	38.7	39.5 and 44.3 "
Goodwin-Rea	46.1	19.5	34.4	42.2 and 49.7 "
Hawks	40.6	22.5	36.9	36.6 and 42.9 "
Hunt	41.0	20.9	38.1	40.0 and 42.0 "
Morison	41.5	21.0	37.5	Ratio uniform.
Myers	43.2	20.7	36.1	40.6 and 44.0 "
Rudd	44.6	19.0	36.4	44.0 and 46.2 "
Wellington	40.0	22.5	37.5	Ratio uniform.
Average	42.79	20.92	36.59	

The apparent interest in all the sections, the set of Messrs. Rea and Goodwin excepted, was to distribute the metal to head, neck and base in a constant percentage for all sections. Messrs. Morison and Wellington do this explicitly, and Mr. Crowell announces this as a principle, though his sections do not exactly agree with it. Messrs. Bouscaren, Felton and Hawks show a tendency to slightly decrease the percentage in the head as the weight increases; Messrs. Goodwin and Rea, to increase the percentage in the head as the weight increases. All other sections (including practically nine of the ten sets), tend to a constant percentage regardless of weight, as shown in the following table, showing the percentage of metal in the head of each section. It has not appeared necessary to construct similar tables for the percentages in neck and base.

PERCENTAGE OF METAL IN HEAD FOR EACH SECTION.

Weight of Section.	40	50	60	70	80	90	100	Average
Bouscaren	44.8	(45.0)	45.3	(45.2)	45.0	(44.0)	42.7	44.5
Crowell	38.7	43.2	40.7	40.9	41.5	41.3	39.2	40.8
Felton	42.8	42.7	43.7	44.3	44.3	41.1	39.5	42.6
Goodwin-Rea	42.2	42.5	44.6	47.5	46.6	49.5	49.7	46.1
Hawks	42.9	40.8	40.3	40.5	41.9	40.9	36.6	40.6
Hunt	40.0	40.7	41.7	41.6	42.0	40.8	40.0	41.0
Morison	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5
Myers	40.6	43.4	44.0	43.7	43.7	43.5	43.5	43.2
Rudd	44.0	44.0	45.7	43.3	44.4	46.2	44.7	44.6
Wellington	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Average	41.75	42.38	42.75	42.85	43.09	42.88	41.74	42.49

WIDTH OF HEAD.—The preferences as to this may be tabulated as follows:

Wt. of Section, lbs. per Yard.	Bouscaren.	Crowell.	Felton.	Goodwin and Rea.	Hawks.	Hunt.	Morison.	Myers.	Rodd.	Wellington.	Average.
40	1.87	2.00	2.12	1.78	1.87	1.87	....	1.82	....	2.12	1.94
50	2.06	2.12	2.25	2.12	2.06	2.06	2.50	2.00	2.19	2.25	2.16
60	2.25	2.25	2.37	2.28	2.19	2.19	"	2.20	2.31	2.37	2.29
70	2.37	2.34	2.50	2.47	2.31	2.56	"	2.37	2.37	2.50	2.43
80	2.50	2.50	2.62	2.55	2.50	2.62	"	2.53	2.50	2.62	2.54
90	2.62	2.72	2.75	2.75	2.75	"	"	2.69	2.56	2.75	2.67
100	2.75	2.87	2.87	2.86	"	"	"	2.84	2.81	2.87	2.73
110	....	....	....	....	....	....	....	....	....	(3.00)	
Total Range, 40 to 100 lbs.	0.87	0.87	0.75	1.08	0.87	0.75	none.	1.02	0.62	0.75	0.79

Messrs. Felton and Wellington submit uniformly varying widths of heads (varying by $\frac{1}{8}$ inch, all others vary irregularly or (Morison's) not at all.

DEPTH OF HEAD.—This may be tabulated as follows:

Wt. of Section, lbs. per Yard.	Bouscaren.	Crowell.	Felton.	Goodwin and Rea.	Hawks.	Hunt.	Morison.	Myers.	Rodd.	Wellington.	Average.
40	1.06	1.12*	1.00	Not tabulated. See Sections.	1.00	0.98	....	1.12†	....	0.90*	1.02
50	....	1.19	1.12		1.12	1.12	1.01*	1.23†	1.19	1.04	1.12
60	1.33	1.25	1.25		1.25	1.28	1.17	1.35	1.37†	1.17*	1.27
70	....	1.44	1.37		1.37	1.39	1.34	1.45	1.47†	1.28*	1.39
80	1.58	1.50	1.50		1.50	1.50	1.50	1.56	1.62†	1.39*	1.51
90	....	1.56	1.56		1.50	1.56	1.66	1.65	1.81†	1.49*	1.60
100	1.70	1.62	1.62		1.50*	1.70	1.82†	1.74	1.78	1.58	1.70

* Minimum. † Maximum.

Angle of Base of Head and Top of Base.—All sections have these two angles alike. Messrs. Crowell, Felton and Rodd use 13 degrees; Messrs. Rea and Goodwin, 13½ degrees; Messrs. Hunt, Morison and Wellington, 1 in 4, or 14 degrees; Mr. Myers, 1 in 4½, or 12 degrees; Mr. Bouscaren, 12 degrees; and Mr. Hawks, 11 degrees.

Fillet Radius.—In every case but one this is the same at both top and bottom of the neck. Messrs. Bouscaren, Felton, Goodwin, Hawks, Hunt, Rea, Rodd and Wellington use ¼ inch; Mr. Myers, $\frac{5}{16}$ inch; Mr. Morison a variable radius varying inversely with the weight of sections from 0.37 to 0.19 inches, averaging about 0.27 inches; Mr. Crowell uses $\frac{1}{16}$ inch for the upper radius, and ⅛ to ¼ inch for the lower radius, the small upper radius being stated to be used for the purpose of improving the bearing of the fish-plate.

Radius of Sides of Neck.—Messrs. Morison, Myers and Wellington use straight sides, and Felton 30 inch radius; Messrs. Bouscaren, Crowell, Hawks, Hunt and Rodd use 12 inch radius; and Messrs. Goodwin and Rea, 9 inch radius.

This cannot usefully be tabulated, as the sides are not of the same form, and can best be judged of from the sections and the percentages of metal in the neck, as shown above.

In explanation of the unavoidable delay in sending out these sections and the above report, the Secretary desires to state that they were held for nearly six weeks after they were substantially complete, to enable members of the Committee to complete their sections, a delay which appeared expedient to secure completeness, as it was found that a quorum of the Committee would not be present at the annual meeting. As all the sections have been in the custody of the Secretary, he desires to state that his own sections were designed quite independently of the rest, and before he had received most of them.

Mr. J. D. Hawks, of the Committee, submits in the accompanying engraving an experiment made to test the effect of flat and thin heads. Two of the Michigan Central 80-pound rails had ½ inch planed off their tops, as shown, and were placed on sharp curves. The rail marked "No. 1" was used on the outside of an 8-degree 18-feet curve for 275 days, during which time 63 800 engines and 447 425 cars passed over it, an average of 232 engines and 1 627 cars per day. The rail marked "No. 2" was used on the inside of a 13-degree 45-feet curve for 655 days, during which time 200 430 engines and 414 615 cars passed over it, an average of 306 engines and 633 cars per day. The result upon the shape of the top was as shown.

Extremities of Base.—These with but one exception are vertical, rounded off with a very short radius at top and bottom, generally $\frac{1}{16}$ inch. The exceptions in radius are: Messrs. Hunt, Myers and Rodd use an upper radius of $\frac{1}{8}$ inch; and Mr. Myers has also a $\frac{1}{32}$ instead of $\frac{1}{16}$ inch radius at the bottom; Mr. Bouscaren has $\frac{3}{32}$ instead of $\frac{1}{16}$ inch radii. Messrs. Rea and Goodwin round the whole corner of the base.

The sections are not designed for precisely the same area of section for each nominal weight, but as this discrepancy is readily corrected, it is neglected in this summary.

Each set of sections is accompanied by a table of dimensions from which this abstract has been prepared, which it is not deemed necessary to reproduce. The explanatory communications sent in by members with their sections are subjoined hereto.

At an informal meeting of the Committee held after the annual meeting it was recommended that the Secretary prepare a set of sections averaging as nearly as might be the individual sections, neglecting any wide deviations which appear in one set of sections only. The Secretary's engagements have not permitted him to do this, but a set having the following dimensions would come very near to such an average section.

Head, 12 inches; top radius, $\frac{1}{4}$ inch; corner radius, $\frac{1}{16}$ inch; lower corner radius, vertical sides; percentage of metal, 41.5 per cent. (neglecting both the Goodwin-Rea and Rodd sections as erratic); width varying by $\frac{1}{8}$ inch for each 10 lbs., and as follows:

Weight of section in pounds	40	50	60	70	80	90	100
Width of head in inches	2.0	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{3}{4}$

Neck, 21 per cent. of the metal; $\frac{1}{4}$ inch top and bottom fillet radii; either straight sides or 12 inch side radius (there appears to be a division of sentiment on this point); thickness as determined by percentage and following dimensions:

Base, 37.5 per cent. of the metal; 13 degrees top angle (as also for under side of head); width same as total height of rail; vertical sides with $\frac{1}{16}$ inch top and bottom corner radii.

Total height and width of base varying by $\frac{1}{3}$ inch for each 10 pounds of section, and as follows:

Weight of section in pounds....	40	50	60	70	80	90	100
Total height and width, inches	3.67	4.0	4.33	4.67	5.0	5.33	5.67
Actual average for "	3.88	3.98	4.28	4.66	4.98	5.32	5.67

Respectfully submitted,

A. M. Wellington,

Secretary of Committee.

The following are the communications sent in by the members of the Committee in explanation of their respective designs:

Mr. G. Bouscaren writes: I send a tracing showing full-size sections for 40, 60, 80 and 100 pounds steel rails, and a tabulated statement giving the dimensions and all other elements of these sections.

The rulings taken for guidance in their preparation are:

First.—Weight of metal, 1 square inch area, 1 yard long = 10.20 pounds. To facilitate comparison we should have agreed on a modulus for the weight of steel at our last meeting. I suppose there will be some variations as to the modulus assumed by the different members of the Committee.

Second.—Height of rail and width of base equal for each section.

Third.—Curvature for top of head, sides of web, corners and fillets, the same for all sections.

Fourth.—Angle with horizontal of bottom surface of head and top surface of flange equal to 12 degrees for all sections. I think this angle should be as small as consistent with the resistance to bending and shearing in the projection of head and flange, in order that the thickness of flange at the edges be as large as possible. This is the weak point of the rail; all fractures generally start there.

Fifth.—Proportions aimed at between areas of head, web and flange:

Head	45	per cent.
Web	20	"
Flange	35	"
	100	"

I have not found any simple rule for interpolation of sizes between extreme sections for intermediate ones. This, however, can receive more attention later.

Mr. J. Foster Crowell encloses tracings of full-size sections of rails from 40 to 100 pounds per yard, four in all, and a tabular statement of dimensions, etc., of sections of 40, 50, 60, 70, 80, 90 and 100 pounds. He says there is a slight inconsistency in the matter of the radii of base fillets, which are given as $\frac{1}{8}$ inch for the 40 and 100 pounds, and $\frac{1}{4}$ inch for the intermediates. This is because he has considered them with reference to the strength of the rail as a beam only. If there should be mechanical difficulties in the way of such a small fillet on the larger section he thinks it would materially affect any other consideration to increase it to $\frac{1}{4}$ inch; but assumes there would be no difficulty in rolling with even less, down to $\frac{1}{16}$th-inch, and has used the latter for the head fillet.

Mr. J. D. Hawks writes: There are some features of my suggested sections herewith sent that I would strenuously insist on retaining. There are other features that I would readily consent to modify. It will be noticed that the width of head in the 90 and 100-pound sections is the same. I think it is as wide a head as could be used with safety in a Northern climate, and think so from the experience of the Michigan Central many years ago with a wide-topped rail, and the difficulty they had by reason of the wheels leaving the track in snowy weather.

I have retained the thin head that we use on the Michigan Central on our 80-pound rail for the 90 and 100-pound sections. There would be no great objection to making the head somewhat thicker for the latter sections if it was considered advisable.

Mr. George S. Morison reports a set of standards, and says: These standards are for rails varying by 5 pounds from 50 pounds per yard to 100 pounds. They are designed in accordance with regular principles which may be applied to any weight of rail, some of which principles relate to the general design of the rail, and some to the three distinctive parts. The dimensions are based on a weight of 490 pounds per cubic foot of steel.

General Design.—The rail is adapted to the form of joint in most general use, which is the angle-plate joint, and also to lay on ties in accordance with the general American practice. The height of rail is made the same as the width of base.

The distribution of metal between the three parts of the rail is fixed as follows:

Head	41.5 per cent.
Web	21. "
Base	37.5 "

These percentages are kept constant for all weights of rail.

Head.—The head is designed in accordance with the recommendations of the Committee of the American Society of Civil Engineers on the Proper Relations to Each Other of the Sections of Railway Wheels and Rails. That is, the top is slightly curved, having a radius of 12 inches; the sides are vertical; the upper corners are rounded with a radius of ¼ inch (0.25), and the lower corners are rounded with a radius of $\frac{1}{16}$ inch (0.16). An inclination of one in four has been selected for the under sides of the head. The width between the parallel vertical sides of the head has been made 2½ inches, and is kept uniform for all weights of rail. This is a radical departure from the usual practice of rail designs, but is regarded as a very important thing. The different weights of rail are determined by the amount of business which they are expected to carry, seldom by the character of the traffic which passes over them. The same wheels run on light and on heavy rail sections. If the weight is to be carried properly down the center line of each rail, the distance between that center line and the gauge line must be kept constant. Furthermore, if the wear on wheels and rails is to approach uniformity, the wearing surface of the rails must be of uniform shape.

The amount of metal in the head is 41½ per cent. of the total metal in the rail, which makes the variation in the cross section of the head for each 5 pounds weight of rail 0.204 square inches. As the only variable in the head is the height, this variation of weight corresponds to variation of height, 0.081 inches for each 5 pounds weight of rail. The heights of head in the table given hereafter and designated as *a*, are calculated on this basis.

Base.—The bottom of the base of the rail is made flat. The sides of the base are two vertical parallel lines. The top of the base is made of two planes having an inclination of one in four. The sides are connected with the bottom and top surface with curves of $\frac{1}{16}$ inch (0.06) radius. The base of all weights of rails are made of similar shape. The 80-pound rail is taken as a basis to start from, the width of base for this rail being taken as 5 inches. This width corresponds to a height of base of 0.90 inches. The dimensions of the base will always be determined by the width and height, and these dimensions will vary as the square root of the weight of rail. The width of base, designated as *b*, and the height of base, designated as *c*, in the table given hereafter, are calculated in this way.

Web.—The sides of the web are made parallel. This arrangement is adopted to prevent using too thin metal for the center of the web in the lighter rails, and to prevent using too small a radius for the fillet connecting the web with the head in the heavier rails. The width of the web measured from out to out of the fillet is kept constant, and this width is fixed at 1 inch. This leaves a width of ¾ of an inch on each side under the head, for the bearing of the angle plates, which is little enough. The height of the web will always be determined by deducting from the total height of the rail (which is the same as the width of the base) the sum of the heights of the head and base. Heights of web, designated as *d*, given in the table below, are calculated in this way. To ascertain the thickness

of the web, the area of the web must first be calculated; from this area a small correction must be deducted to correspond to the four fillets and the triangles above and below the central height, and the remainder must be divided by the height. The correction to be made is smaller than would at first be expected, and has been taken as 0.054 square inches, which is slightly too much for the lighter rails and slightly too little for the heavier, but the error is not enough to be material. On this basis the thickness of the web, designated as *e*, given in the table hereafter, has been calculated. The radius of the fillet at top and bottom is also a variable. If the angle here was a right angle, it would be equal to one-half the difference between 1 inch and the thickness of the web. As, however, there is an inclination of one in four, the radius is 1.32 times this difference. The radii of the fillet designated as *f*, given in the table below, have been calculated on this basis.

General.—The method of determining all the variable elements in the several sections of rails having been explained, it remains only to tabulate the results. For convenience the elements have been designated by letters as follows:

Height of Head.....	*a*	Height of Web.....	*d*
Width of Base.....	*b*	Thickness of Web.....	*e*
Height "	*c*	Radius of Fillet.....	*f*

The table is as follows:

Weight of Rail.	Head.	Base.		Web.		
	a.	*b.*	*c.*	*d.*	*e.*	*f.*
50	1.01	3.95	0.71	2.23	0.44	0.37
55	1.09	4.15	0.75	2.31	0.47	0.35
60	1.17	4.33	0.78	2.38	0.50	0.33
65	1.26	4.51	0.81	2.44	0.53	0.31
70	1.34	4.68	0.84	2.50	0.56	0.29
75	1.42	4.84	0.87	2.55	0.58	0.28
80	1.50	5.	0.90	2.60	0.61	0.66
85	1.58	5.15	0.93	2.64	0.64	0.24
90	1.66	5.30	0.95	2.69	0.67	0.22
95	1.74	5.45	0.98	2.73	0.70	0.20
100	1.82	5.59	1.01	2.76	0.73	0.19

From this table the sections given on the accompanying sheet have been drawn.

On the first section (which is that of an 80-pound rail) all the constants are marked, these being the width of head, the width outside the fillets, and the radii of all convex curves. On the other eleven sections, which are marked with their respective weights, the veritable dimensions are marked.

Mr. E. T. D. Myers writes: My endeavor has been to base my suggestions upon the recorded recommendations of a committee of the Society, and also upon the deductions of those who have been close observers, whether as makers or users of rails. Whilst these sections do not contemplate the use of base plates, I am nevertheless one of those who believe that better methods of increasing both the bearing of the rails and their hold upon the ties, will, in the near future, come into use, and with them substantial modifications in the form of rails.

Mr. Thos. Rodd writes: I send a little diagram showing approximately how the 80-pound rail would wear down on a curve. The unit strains in compression, considering the rail as a beam, non-continuous, at 20-inch bearings, are given for the original section and for the reduced section, allowing in each case 40 000 pounds as the extreme fiber strain. The little table subjoined gives the center breaking load of the original section, and of the worn section; the depth of wear being the same in each case, and as shown in each section; and the allowance being also made for side wear, as shown on the section, for curves, the extreme fiber strain being taken as 40 000 pounds. The supplemental drawing of 80-pound section shows the graduation of the strains between the outermost fibers and neutral axis, at center of span. In assuming the high extreme fiber strain of 40 000 pounds it should be borne in mind that the less strained part tends to help the more strained part; furthermore, the stresses shown exist only at midspan since they are dependent on the bending moment, which decreases from the middle towards the end of the span, and with it the intensity of the horizontal stress also, so that the strain varies not only in the vertical direction on both sides of the neutral axis, but also in the direction of the length of the rail.

Original Section.		Worn Section.		
Weight.	Center breaking load.	Per cent. of head worn.	Center breaking load.	Per cent. of original strength remaining.
50 pounds.	43 200 pounds.	35.0	29 800 pounds.	69.0
60 "	52 700 "	33.8	38 100 "	72.3
70 "	68 300 "	31.8	51 200 "	75.0
80 "	80 800 "	30.1	60 600 "	75.0
90 "	93 600 "	32.9	78 900 "	84.3
100 "	111 400 "	28.0	98 000 "	88.0

Mr. A. M. Wellington writes: The following dimensions are assumed by me as constants throughout the sections:

12 inches top radius,
$\frac{1}{4}$-inch corner radius,
Vertical sides,
$\frac{1}{16}$-inch lower corner radius.
} Pursuant to recommendations of former Committee on Form of Rails and Wheels, and for the reasons stated in their report.

1 to 4 (14 degrees 02 inches) angle of lower side of head with the horizontal, adopted instead of 13 degrees, which is perhaps more usual, for the reason that it does not sensibly diminish the efficiency of the fish-plate bearing, while fish-plates are used, and gives a slightly better form of section if fish-plates are not used. I do not consider the difference of much importance, and should be ready to assent to 13 degrees if preferred by a majority of the Committee.

Of the Neck.—$\frac{1}{4}$-inch fillet radii, as the best compromise between giving as good a fish-plate bearing as possible (requiring a short radius), and easing the transition between neck and head and base, which requires a long radius, but in my opinion not a very long one, when the neck is made fairly thick.

Vertical Sides.—In order that the thin metal furthest removed from the top and bottom masses may not cool too rapidly, the neck is made fairly thick for the same reason, and to avoid concentrating too much of the work done in rolling on the neck. If it be time, however, that the extra work done on these masses suffices to keep them hot

enough, my impression is that these sections might be improved by removing some metal from the neck and adding it to the extremities of the base.

Of the Base.—$\frac{1}{16}$-inch corner radii, Vertical sides. } The lower corner of the base should not be sharp, as it tends to promote cutting.

The upper corner should have some small rounding. There should be as much of a vertical face as possible to give bearing against spikes.

1 to 4 angle of top of base with horizontal. I adopt this partly to make it the same as the head (though there is no longer any special reason why the two should be alike).

Distribution of Metal.—I adopt for this: Head, 40 per cent.; neck, 22½ per cent.; base, 37½ per cent. I am satisfied that there is no real gain in life of rail, but rather loss, in putting more than 40 per cent. of the metal in the head; and that the neck should not be too thin. It might be well, however, to take 1 per cent. of the metal from the neck and use it to thicken the extremities of the base.

Total Height of Rail.—I assume 4 inches for a 50-pound rail, 5 inches for an 80-pound, and 6 inches for a 110 pound, as dimensions which experience favors, and by filling in the remaining heights evenly obtain the following total heights:

Wt. of rail, lbs. per yd.,	40	50	60	70	80	90	100	110
Total height, inches,	3.67	4.00	4.33	4.67	5.00	5.33	5.67	6.00

Width of Base.—I assume this as the same as the base, in accordance with current practice, up to and including 80-pound rails. Beyond that point it is not rational to design rail sections with a view to their resting directly on the tie, and if a base-plate is used it seems better to retain a constant width of 5 inches for all sections from 80 to 110 pounds inclusive. Good rolling of the heavier sections is thus promoted.

Width of Head—I believe this should be as wide as possible for all sections, and therefore that it should increase about in proportion with the height. It is desirable, on the other hand, to give some weight to the desirability of having all rail-heads of the same width. With perfectly flat rail-tops this would be quite important; with a 12-inch top radius, I believe it to be of very minor importance, for the reason that a worn tread naturally wears to about a 12-inches radius for a width considerably wider than the widest rail-head, and therefore fits well any rail-head not over 3 inches wide, on the principle of the ball and socket joint. Only in very rare instances, I believe, could the variable width cause the load to come on the corners of the rails. I therefore adopt the following widths of rail-heads:

Wt. of rail, lbs. per yd.,	40	50	60	70	80	90	100	110
Width of head, inches,	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{7}{8}$	3

These constants being given, and assuming the rail to require 0.98 square inches section for each 10 pounds per yard, we have the following distribution of metal in the several sections, which I extend to 110 pounds, as rails of that weight are already in use on this continent, on the Chignecto Ship Railway, and may be expected to be used elsewhere.

Sq. ins., p. c.	40 lbs.	50 lbs.	60 lbs.	70 lbs.	80 lbs.	90 lbs.	100 lbs.	110 lbs.
Head.... 40	1.57	1.96	2.35	2.74	3.14	3.53	3.92	4.31
Neck.... 22½	.88	1.10	1.32	1.54	1.76	1.98	2.20	2.43
Base 37½	1.47	1.84	2.21	2.58	2.94	3.31	3.68	4.04
Total... 100	3.92	4.90	5.88	6.86	7.84	8.82	9.80	10.78

Given these areas, and top slopes of 1 to 4, the center and side heights of the base are readily computed as follows: Add 0.0034 square inches to the area, to give what it would be if the corners were made sharp instead of with $\frac{1}{16}$-inch corner radii.

The base may then be divided into two parts: a rectangular base, of width w and height x, and an equilateral triangle, of width w, height $\frac{w}{8}$. We then readily obtain $x = \frac{A - \left(\frac{w}{4}\right)^2}{w}$,

and

Total center height $h = \frac{A + \left(\frac{w}{4}\right)^2}{w}$

As a check, $h - x = \frac{w}{8}$.

The head may be divided by a horizontal line, tangent to the upper corner curves slightly prolonged, into two parts: (1) a very small segment of a circle of 12 inches radius, whose base (letting w = the width of head in inches) is $w - 0.5$, and whose center height is h given very accurately by the formula:

$$h = \frac{\left(\frac{w - 0.5}{2}\right)^2}{24}$$

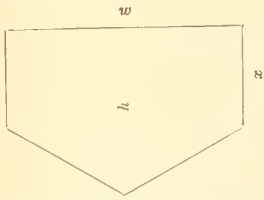
While its area is given accurately by the formula:

$$A = \left(w - 0.5\right) \times \frac{2}{3}\, h.$$

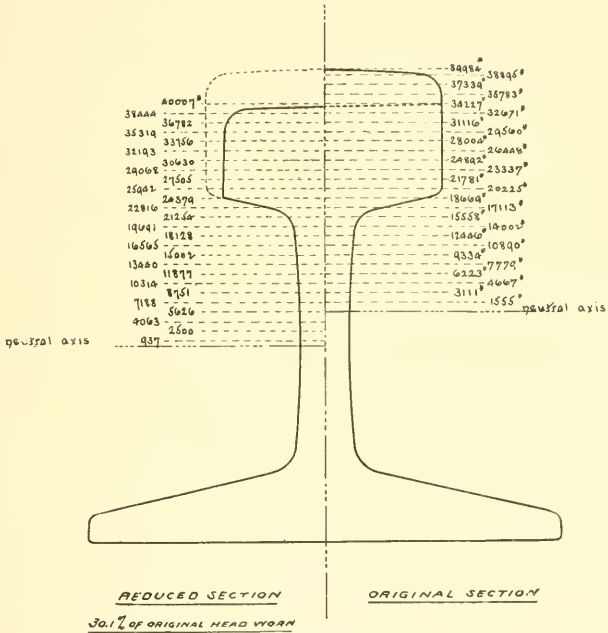
In this way the center height and area added by the use of a 12-inch top radius, instead of a flat-top, is found to be as follows:

	40 lbs.	50 lbs.	60 lbs.	70 lbs.	80 lbs.	90 lbs.	100 lbs.	110 lbs.
Center height, inches...	0.027	0.032	0.037	0.042	0.047	0.053	0.059	0.065
Area, square inches.....	0.003	0.005	0.015	0.024	0.034	0.047	0.060	0.076

Deducting this small area from the total allotted to the head, and on the other hand adding to it the small quantity (0.032 square inches) which would be required to fill out the rounded corners to square corners, and we obtain an area of the same general form as the base, as shown in sketch, the width and total area of which are known, from which h and x (if desired) are readily computed. Adding to h the center height of the crowning, as already determined, we obtain the total center height of the head, as shown on sections.



The total height of the rail, less the determined center heights of base and head, gives the center height of the neck, from which and its known area the thickness is readily determined.



80 LB SECTION

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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(Vol. XXIV.—February, 1891.)

THE CHIGNECTO SHIP RAILWAY.

By JOHN F. O'ROURKE, M. Am. Soc. C. E.

The nineteenth century is distinguished for its marvelous advancement in all the arts and sciences connected with communication, or what is the same thing and more, by the development of engineering. At the beginning of the century mail coaches and carrier wagons were the mediums of inland commerce, aided by an occasional river or canal boat; and "old ocean's grey and melancholy waste" was quickened by nothing more speedy than a sailing vessel. The exchange of ideas was slow, traveling between distant points seemed interminable, and the cost of land transportation limited the exchange of ordinary commodities to a small home

market. The gradual extension of canals was a great step forward, as they enabled large bulks to be moved with the small forces then known, reducing the cost of transportation and affording the products of the farm and forest an outlet. But speed is dependent on power, and that great and essential necessity was still wanting. Next steam and electricity came into use, and with them steamships, railroads and telegraphy. Then awoke the spirit of the age, bringing all men in touch and making the world one great market and auditorium. These things developed from small beginnings, like all achievements over nature, and they have yet a long journey to make in the direction of perfection; but the engineer of to-day, with the mighty advances of his predecessors and with the banded sympathy and aid of his greater brothers, is rapidly getting them nearer and nearer to the goal. Many things are in a satisfactory state of advancement, and every day sees something newer and more admirable. The railroad trains of to-day are wonders. So are those marvelous steamers that unite the continents; swift, stately and safe, as obedient to control as the most docile pony, yet often possessing more power than all the horses that would mount an army. The thousand and one other forms in which the genius and progress of engineering show themselves are wonders, and constructive ability has reached the point that it is a common saying, "Anything can be built if you have the money." In such an age, what is more natural than that time-honored methods should be departed from when there are others more fitting. Heretofore artificial works for the transport of vessels have been canals.

There are many situations where commerce requires such transit, and where canals are impracticable because too costly or for scarcity of water.

A ship railway costs less money, needs no water, and can be built almost anywhere.

Many engineers, notably the late Capt. James B. Eads and Mr. E. L. Corthell, M. Am. Soc. C. E., in the United States, and Mr. H. G. C. Ketchum, M. Inst. C. E., in Canada, have advocated ship railways as substitutes for canals. Messrs. Eads and Corthell, finding capitalists shy of investing in what, to them, was visionary, applied to Congress for aid without success. Mr. Ketchum's appeal to the Dominion Parliament was because of a similar reason, and resulted in a subsidy sufficient to insure the construction of a ship railway across the

Isthmus of Chignecto, between the Bay of Fundy and the Gulf of St. Lawrence.

This will be the first application of rails to navigation, and Canada has secured the honor by guaranteeing for twenty years an annual sum equal to one two-thousandth the yearly receipts of the New York Custom House. As when built it will, most likely, be self-supporting, Canada may be said to have purchased the honor with a little accommodation.

If ship railways will do all that is claimed for them, and it is morally certain that they will, a new era is about to open in transportation. A ship is not a fish, though that seems almost asserted in the stress that is laid on the popular statement that water is its natural element; and usage makes it difficult to think of a ship apart from water. It is lost sight of that a ship is a land-built structure of the strongest and stiffest design, fitted to withstand the tossing and buffeting of the highest seas and the wildest storms. Now pounded and overswept by a colliding wave, and the next moment bare of water almost to the keel, while all the time, perhaps, the rocking and plunging and the mighty wind is tearing the rigging and snapping the spars. Nevertheless, vessels that have lived through fifty years of such life are not uncommon.

Light-houses and breakwaters tell enough of the fury of the sea to ridicule any pretense of hydrostatic pressures around ships excepting in still water; or that naval constructors build ships dependent on the water pressure to keep the cargo from bursting out the sides; or that water is the natural element of ships in the caressing sense used by the good people who object to ship-railways as snares of destruction.

It therefore follows that a ship resting on blocks at short intervals along the keel and bilges, is adequately supported; and that if borne on a suitable carriage over a smooth and rigid roadway, it will make the journey with as much ease as under the most favorable conditions afloat, or, generally speaking, that a ship is as well adapted to traveling by rail as by water.

The Chignecto Ship Railway will soon be an accomplished fact. Others will quickly follow, and it takes no gift of prophecy to forsee the time when every isthmus will pass ships dry shod, if need be, and when inland cities will be open to navigation with rails, and the freight-car and the ship will occupy adjoining sidings at the warehouse and factory. It is not beyond belief that a twentieth-century siege may be conducted by war vessels on temporary roads, opposed by traveling fortresses on strategic railways that defend every approach.

Fig. 1 is a map of Nova Scotia, showing the relation of the ship railway to the coasting trade; also the saving of distance that the new

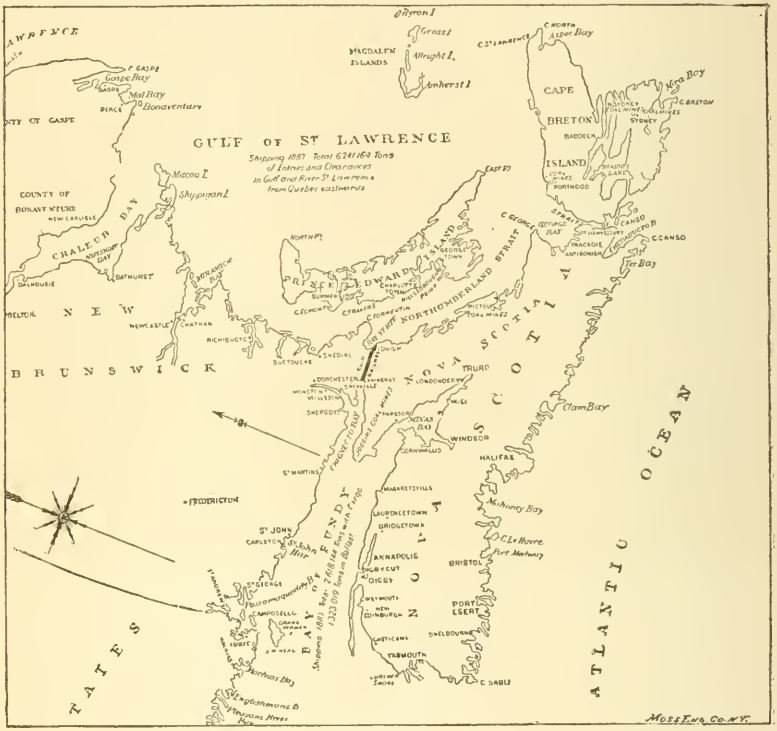

FIG. 1.

inside route will effect for vessels that are now obliged to navigate around the circuitous and dangerous coast.

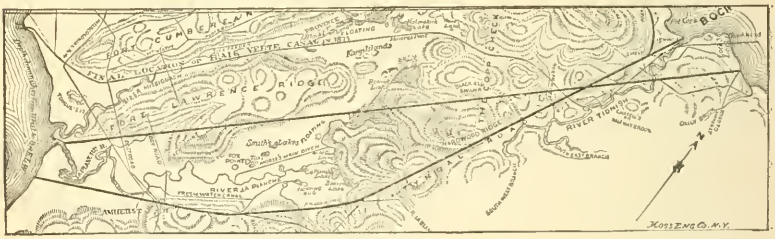

FIG. 2.

Fig. 2 is a topographical map of the Isthmus of Chignecto, and shows the location of various canal and ship railway lines proposed at different times, and the present line that is now under construction.

The ship railway will be 17 miles long, and will be on a straight line from end to end, running through a country moderately rolling, with only one watercourse to cross, and generally favorable to the rectilinear location, and the two-tenths per cent. maximum grade adopted.

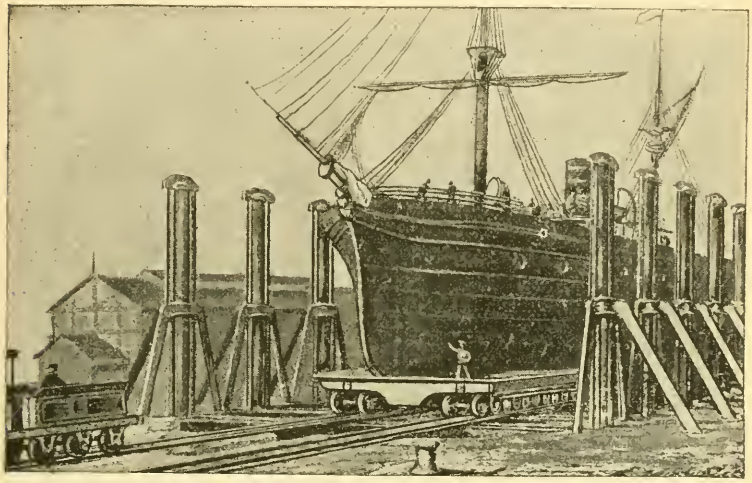

Fig. 3.

Fig. 3 shows a vessel as it will look in the lifting dock, ready for transportation. The vessel is seen resting on blocks along its keel and bilges, supported on platform cars nearly 40 feet in width and carried by two hundred and forty wheels arranged in four lines to run on two tracks of standard gauge, 18 feet between centers. The gridiron on which the ship and cradle (as the cars are called) move up and down in the lifting dock, is like the deck of a bridge, with the floor beams arranged in pairs, slightly separated to admit the hydraulic presses between them, and connected by track stringers under the rails, as is common in bridge work. The hydraulic presses are twenty in number, and are designed to lift a vessel carrying 1 000 tons of cargo, together with the cradle and gridiron. They are arranged in two lines, 21 feet longitudinally and 64 feet transversely between centers, and have a maximum stroke of 40 feet. The cross-heads on the inner cylinders are attached to the floor-beams with eye-bars a little longer than the stroke of the presses.

When a vessel is to be lifted, the gridiron, with a cradle on its tracks,

is lowered, and the vessel is hauled into position with hydraulic capstans. Water is then forced into the presses until the keel blocks are brought to a bearing, next the bilge blocks are drawn into place and the pumps are again started, raising the gridiron in less than ten minutes to a position where its tracks are slightly above those of the railway. A connected system of heavy iron chocks, supported by the masonry, is then shot under the ends of the girders by hydraulic power, the gridiron is lowered to a bearing on them, and its tracks are connected with those of the railway, of which it is now a part. Two locomotives will haul the ship across the isthmus in less than two hours, and a reverse operation to that described speedily restores the ship to the water.

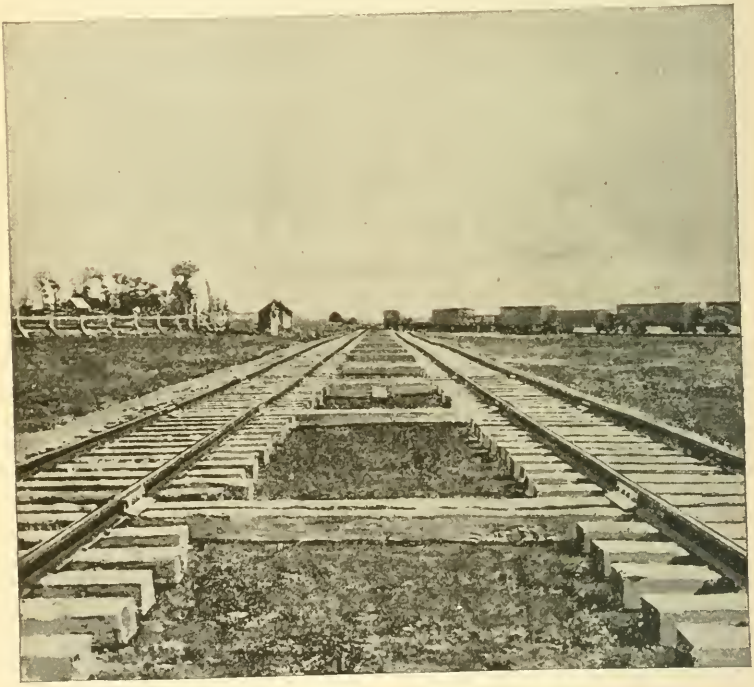

Fig. 4.

Fig. 4 shows the railway track. It is composed of 110 pound rails laid on 9 feet x 12 inch x 7 inch ties; the two ties at the joints being 27 feet long and of the same section, connecting both tracks and preserving the gauge of the inner rails. The road will be stone-ballasted throughout, and will be tested with rolling loads of a greater weight than the

maximum size ships, to insure freedom from subsequent settlement, and smoothness and rigidity when operations begin.

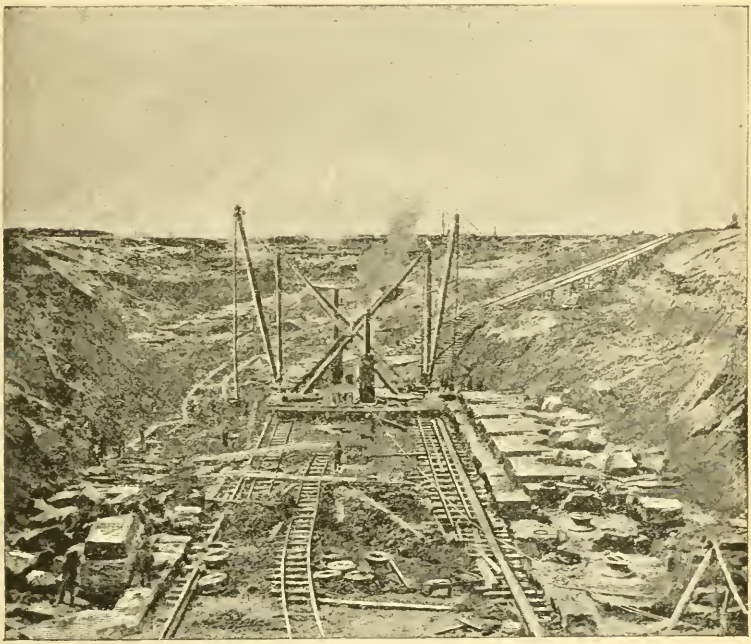

FIG. 5.

Fig. 5 shows work in progress at the Amherst end, that at Tidnish being in a similar state of advancement. The heavy cutting at Tidnish is 1½ miles long, and contains over 500 000 cubic yards; composed of hard pan, boulders and rock, of which less than 10 per cent. remains to be excavated. There is a 30 feet stone arch over the Tidnish River, which is finished. The track is laid for 13 miles from the Amherst Basin and ballasting has been progressing for several months.

The termini differ greatly, because of the immense tides in the Bay of Fundy. At the Tidnish terminus, where the tides are but 7 feet, a lifting dock with moles attached and a dredged basin and channel, comprise the main works. The Amherst terminus is situated at the mouth of the La Planche River, where there is a variation of over 50 feet between extreme high and low tides. Anchorage at low water is impracticable near the shore, so a tidal basin is excavated inshore and connected with the

harbor by a channel. The basin is 500 feet long, over 300 feet wide, and 50 feet deep, the bottom being about at the level of low water. The entrance gate and sea walls are of heavy masonry, the top being at the common level of the top of the lifting dock and the railway. The top of the gate proper is 17 feet lower, or 12 feet below high water spring tide, and retains a minimum depth of 32 feet in the basin. The lifting dock is at the inner end of the basin and is 270 feet long. Vessels will be able to enter or leave the basin during the higher stages of the tide, while the excellent anchorage off shore and the large storage capacity of the basin, insure a continuity of traffic uninterrupted by the extraordinary fluctuations of the bay. Sir John Fowler and Sir Benjamin Baker are associated with Mr. Ketchum as the engineers. Messrs. John G. Meiggs & Son are the contractors for the entire work. The contract for the graduation, masonry, track, terminal and harbor work, etc., being re-let by them to Messrs. Dawson, Symmes & Ussher; and that for the hydraulic plants of the lifting docks to Messrs. Easton & Anderson. (A more extended paper on this important work is promised by Mr. O'Rourke, on its completion.)

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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(Vol. XXIV.—February, 1891.)

SELF-PURIFICATION OF FLOWING WATER AND THE INFLUENCE OF POLLUTED WATER IN THE CAUSATION OF DISEASE.*

(A BIOLOGICAL STUDY.)

By CHARLES G. CURRIER, M.D., Mem. N. Y. Acad. of Med.

WITH DISCUSSION.

Our water sheds being in great part composed of diluvial and alluvial formation can, besides holding much in the depression of their uneven surfaces, take up and retain a varying amount of the water precipitated from the clouds, or coming directly from condensation of atmospheric vapor or otherwise reaching the earth. It may be considered that dry, sandy soil takes up 45 per cent. of its volume of water;† while dried turf can absorb perhaps ten times its weight of water by reason of the great surface created by the enormous number of minute particles. The finely divided elements of the soil can furthermore, by their capillarity, cause water to rise through their substance to a considerable

* Read before the American Society of Civil Engineers, November 5th, 1890.

The first pages are introductory, and added chiefly as a succinct reply to questions propounded by members of the Society at the time of the reading of the paper. For brief explanation of the bacteriology involved, see Appendix (page 42).

† Meister : Soyka, *Der Boden*, page 83.

height, which in loam is many times greater (though the rise is there much slower) than in the coarsest earth (gravel). The hydrostatic power of earth is much augmented by the presence in it of organic matter,* and the cleaner the ground is kept the drier it is.

More or less deep in permeable earth, underlain with impermeable strata, water is regularly found completely filling all the pores, and this is called the "ground-water." Not to explain at length the zonal differences of the layer of earth between the surface of the ground and the surface of the ground-water, it may be said briefly that water passes rapidly through this when of coarse gravel, while in very fine soils many months may in our region be required for a given water to make its way from the air down to the surface of the ground-water. By taking up certain constituents and losing others it may have considerably changed its character in the downward passage. Most varieties of the micro-organisms which swarm on and near the surface of the ground are less able to find the conditions favorable to their life and activity after descending a few feet. Some porous soils seem to be permeable to bacteria for less than 6 feet. Hence the ground-water is often quite free from bacteria. The best deep springs show few or none of these, and the uncontaminated water flowing directly thence is, unless highly impregnated with minerals, the most wholesome of beverages.

These underground bodies of water may be regarded as subterranean lakes or water-courses, usually flowing several feet daily toward the streams or lakes draining the basins in which they are, and the level of the ground-water is lowest near such draining streams or bodies of water. Hess† found that in northern Germany such water moved sometimes more than 100 feet per day. Thiem‡ judged from observations on the Bavarian plateau that from 9 to 25 feet was an accurate estimate of the daily advance of the ground-water there measured. It is largely owing to such enormous and well-protected reserves that the lakes and streams of our region maintain the average level to which they tend to return when temporarily lowered by drought or when swollen by freshets.

For about thirty-five years, since first v. Buhl and Seidel called attention to the principle, v. Pettenkofer and others have insisted upon what they consider the causal relations existing between the moisture changes indicated by the varying height of the ground-water

* Hoffmann: *Archiv für Hygiene*, II, 145.

† *Zeitschrift des Architekten und Ingenieur Vereins* in Hannover, XVI.

‡ *Journal für Gasbeleuchtung und Wasserversorgung.* 1880.

level and the prevalence of epidemics which, they claim, are not much if at all, influenced by purity of drinking water as such, by mere filth or any other than this particular element which induces the manifestations of activity on the part of the causative germ. Soyka's experiments* led him to consider that in a long, dry spell of weather, such as precedes the lowering of the ground-water level, there is a more or less uninterrupted capillary flow towards the surface. With this, living micro-organisms that may be in the ground are carried upward into the outer layers of the soil. From the evaporation of this water the microbes remain on the surface or somewhat deeper. With rain they may be washed along or return into the ground. If dry weather persist, they may be stirred up with the dust and in their exsiccated form carried far through the air, as has been rendered evident by several examinations where they have been found many miles out above the open ocean. After the evaporation of water coming up to the surface, the previously-dissolved substances remain in the upper layers of the ground, and the water there becomes a more concentrated solution of these substances. The ground-water is in itself quite harmless. Its significance is as an indicator of the fluctuation in the moisture of the ground, and the cleaner the earth is kept the less importance is attached to hydrometric changes.† While it is not denied that germs may have to be present to cause the disease, this doctrine claims that they can produce disease only when the local conditions favor their activity.‡

Repeated and careful observations have made those of the Munich school who contend for this "localistic" theory insist that, excepting, of course, where by artificial drainage we intentionally cause water to be drawn away from the ground, such a disease as, for instance, typhoid fever, increases as the ground-water sinks, and no considerable epidemic of typhoid occurs without at the same time a sinking of the ground-water level. No considerable typhoid epidemic occurs in the period of a large rise of the ground-water, say the champions of the interpretations which v. Pettenkofer has given to the facts as observed at Munich.‖ This view is, however, not in consonance with the facts of all epidemics.

The majority of practical hygienists do not indorse these views in their fullness. The definite advances made of late years by biological

* Prager med. *Wochenschrift*, 1885.

† Dr. Max v. Pettenkofer : Deutsche med. *Wochenschrift*, Nov. 28, 1889, page 977.

‡ Dr. Mex v. Pettenkofer : *Archiv für Hygiene*, iv, 249; v, 353.

‖ Prof. J. Soyka: *Archiv für Hygiene*, vi, 257.

study have given further and further ground for believing that, among other diseases, such ones as typhoid and probably cholera are solely caused by the vital activity (within the human organism) of the specific bacteria of these diseases. Inasmuch as a great number of sporadic and epidemic attacks of these scourges have been clearly traced to the consumption of water containing the infective elements of these diseases, and no other factor has there been constant or frequent, this belief is called the "drinking-water theory." While emphasizing the baneful effect of polluted drinking-water, it is of course admitted that unclean ingesta or anything that introduces these living bacteria into the alimentary canal, may be the means of carrying the infection into the system.

In the case of cholera the localistic theory seems more difficult to refute than in the case of typhoid. Yet in India, as elsewhere at the time of each epidemic, much circumstantial evidence has accumulated to make us suspect that the presence of the infective element in the alimentary canal is the prime factor in inducing the disease. Bacteriology has strengthened this opinion from the time when Koch* found the peculiar spirillum in cholera dejecta and in the intestines of those who had died from cholera. The presence of this characteristic micro-organism in the water of a certain tank was demonstrated by him, together with the fact that in the neighborhood in question, only those who had drunk of this water had the disease. The facts were presented with Koch's unsurpassed precision, and carried more conviction than any single one of the various similar histories. Still no theory suffices to explain the exemption of certain cities (as Stuttgart, Salsburg, Innsbruck, Hanover, Versailles, Rouen, Lyons, and others) from any outbreak during the various epidemics. These important centers of travel and commercial intercourse did not succeed in barring all entrance of infection, and their supplies of potable water were not conspicuously superior.

On page 211 of Koch's report (1887), an impressive diagram is given to show the permanently decreased cholera mortality in Calcutta since November 1st, 1869, from which time the city has been supplied with hydrant-water which, on analysis, seems very good. The tank water formerly used in the city (as even now in the suburbs) was—like nearly

* Bericht über die Thätigkeit der zur Erforschung der Cholera im Jahre, 1883, Entsandten Commission, page 182. Berlin, 1887.

everything in India*—exceedingly filthy. The water of the polluted Hoogly River, likewise more used formerly than at present, contained 250 000 bacteria per c.c. when examined by Koch.

Among those who consider that intelligent admission of ignorance is preferable to subserviency to a theory, it is proper here (because of his great and favorable opportunities for many years of observing cholera in its endemic haunts) to mention the statements of Surgeon-General Cunningham.† He observed that some districts in India are wholly immune at all times, regardless of the contaminated state of the water supplies. In his experience, disinfection of cholera dejecta is useless, and drinking-water does not cause cholera. Unlike some who have never been near India, or have not remained there for many weeks, he considers that railways have not in any way influenced the spread of epidemics of cholera in India either in time, place, or extent. It is needless to say that others dispute the accuracy of these inferences, and there is a great amount of evidence on both sides.

Selecting then the best portions from these conflicting theories, we find that both condemn a drinking-water having many‡ and various bacteria, and both call for abundant supplies of good water for individual and public uses. At the last International Congress, in Vienna, in 1887, where the leading hygienists of the world were gathered—and among them the high priests and acolytes of the ground-water theory—there was an unanimous and unmistakable expression of the opinion that, in order to the maintenance of a high degree of health, cities need an abundant supply of the purest water attainable by them.

The green algæ and the diatomaceæ are found only in waters well supplied with light and air, with no excess of organic matters, and free from regular sources of infection. But the written and oral expression of the opinions of others familiar with the subject, as well as an extensive personal observation, leads me to believe that a water containing a large number of bacteria, especially if many varieties are detectable in it, is objectionable as a beverage so long as it has not undergone the sterilizing influence of heat, or of other adequate means of purification. No sufficiently prolonged and repeated clinical observations by medically-qualified workers have yet accumulated, to determine just what harm, if any, the ordinary earth (and water) bacteria can produce when extensively consumed by human beings. Most of these micro-organisms are classed as harmless.

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* J. B. Hamilton, M.D., *British Med. Journal*, October 4th, 1890, p. 787. (Enteric fever in India.)

† Cholera. What can the State do to prevent it? By J. M. Cunningham, M.D., etc. Calcutta, 1884.

‡ Even in Emmerich und Trillich's Book, München, 1889, page 168, we find this admitted.

Unlike pathologists in some other countries, we do not here so often detect the ova of tænia and other intestinal parasites as having come from the ordinary water supply;* and although we here, of course, recognize that some nematodes develop first in water, and are thence carried to man, we are not confronted with such unpleasant statistics as Sievers derived from his obductions in Kiel.†

From the time when Dr. Michel‡ first called attention to the influence of contaminated water in causing typhoid fever (1855), and Snow in 1848, said that cholera was due to the use of infected water, an enormous mass of evidence has been constantly accumulating and has caused nearly all physicians among us to believe that such influence has usually been operative in those cases that they have met, even if for various reasons the exact source of the infection could not be traced. Furthermore, numerous attacks of diarrhœal disorders have been explainable in no other way.

Endorsing Naegele, the botanist, and other partisans of the extreme ground-water theory, Emmerich‖ performed a series of experiments upon animals, and from these inferred that decomposing organic matter taken with water into the stomach could not cause harmful symptoms. As evidence of his sincerity he daily, for two weeks, drank from one to two pints of very foul water taken from a hospital brook, which to the naked eye and to chemical tests was distinctly infected with sewage and which showed a large amount of chlorides, ammonia, and various organic substances. During the first three days he noticed slight gastritis, yet during the remainder of the fortnight no ill-effects were recognized. A month later, having acquired a gastro-enteritis, he again tested upon himself in the same way the effect of the same sort of water but observed no detriment to his health. Very few could be induced to repeat such unpleasant subjective experiments, and many such would only prove that polluted waters vary in character and are not at all times, and under all circumstances, demonstrably harmful. Most persons would, if solely for æsthetic reasons, strongly object to drinking freshly-polluted waters.

Prof. Chandler calls my attention to the immunity of Albany, N. Y. (during the last two decades), from any serious outbreak of disease attributable to bad drinking-water, although the Hudson River, supplying water for its hydrants, is at times contaminated with the city's own sewage and certainly with that of the neighboring city of Troy. I have never investigated the water supplied to Albany, but am not surprised to hear (from those who have inquired) that the citizens regard the water with suspicion and suspect it of causing diarrhœal and other disorders.¶ It would seem as though cholera germs getting into such a water would greatly augment the danger of a cholera epidemic.

The experiments of Prof. J. v. Fodor§ show that unless steril-

* Knoch: *Virchow's Archiv*, xxiv, 453.
Blanchard: *Revue d'Hygiène et de police sanitaire*, le 20 Sept. & le 20 Oct., 1890.
† Sievers: Schmarotzerstatistik, Kiel, 1887.
‡ See *Annales d'Hygiène Publique*, etc., Dec., 1889, page 541.
‖ *Zeitschrift für Biologie*, xiv, 563.
¶ See New York City papers of Jan. 25, 1891, for mention of typhoid epidemic at Albany caused by drinking river water.
§ *Archiv für Hygiene*, iii, 118.

ized, as by boiling, foul waters may be assumed to be dangerous, even if not obviously so; for they tend to cause some degree of putrid infection which, however vague, may, like extreme hunger* and other "cachexies" act to weaken the system and render it less resistant to infection. Besides abundant laboratory evidence of this sort, the most impressive of tests have unintentionally, but in general with apparently very serious results, been made by so many bodies of men and communities that the mere enumeration would cover many pages. When more than one-tenth part of a population is attacked by typhoid after drinking of the water from a presumably pure mountain stream, stored for consumption, but into which a small amount of typhoid dejecta had been introduced (to cite the familiar experience of Plymouth five years ago); the fact that the majority of those using the same water, perhaps uncooked, revealed no symptoms of the malady, does not invalidate our right to interpret these epidemics by the light of our present knowledge and so infer that a polluted drinking water may be very dangerous. If Vienna, paralleling London's well-known experiences with cholera and typhoid, averaged many times the number of deaths from typhoid when she supplied her people with the water of the swift, "blonde" Danube, that she has had since the hill-spring supply has been furnished, the fact is very significant. But here, too, v. Pettenkofer has come forward with his keen interpretation of the facts and has tried to show that infected water had nothing to do with the causation of the disease.

There are a few authentic laboratory experiments† which go to show that, in ordinary water, disease-producing bacteria are, at least in some cases, more or less speedily destroyed by the hardier saprophytic varieties that abound in all supplies of doubtful quality. But since first Moers‡ found the bacillus of typhoid in water suspected of having caused the disease (the finding receiving Prof. Gaertner's confirmation when it was later questioned) and Michael‖ likewise detected these (under corresponding circumstances and was endorsed by Prof. Johne),

* Canalis und B. Morpurgo, Fortschritte der Medicin, Sept. 15 and Oct. 1, 1890.

† Arnould: *Revue d'Hygiène*, ix, 27. Freudenreich: Annales de l'Institut Pasteur, iii, 200. De Giaxa: *Zeitschrift für Hygiene*, vi, 102; Annales de Micrographie, 1890. Garré: *Correspondenzblatt der Schweizer Aerzte*, 1887. Karlinski: *Archiv für Hygiene*, 1889, 113-432; also 1890, page 464. Kraus; *Archiv für Hygiene*, 1887, 205. Zagari: Giornale internazionale delle scienze mediche, ix.

‡ Ergänzungshefte zum *Centralblatt* für allgem. Gesundheitspflege, ii, 2, 144 (in 1886).

‖ Fortschritte der Medicin, iv, ii, 353 (in 1886).

For list of some others who have detected the genuine typhoid germ in suspected water, see Uffelmann's Jahresbericht, 1890, page 224.

a considerable number of competent bacteriologists have in different countries reported similar results. Others have verified these facts by adequate laboratory trials. So we are to-day allowed to believe that the micro-organisms which cause some diseases can, despite the antagonistic influence of ordinary bacteria and influenced by various conditions which we as yet do not clearly understand, live at times for at least several days in natural and artificial waters of varying degrees of purity and still retain enough of their specific vitality to induce more or less serious cases of disease. The terrestrial conditions influencing the activity of these presumable causes have not yet been established with sufficient accuracy.

Chemistry affords us no sufficient test of the freedom of a water from the infective principles which cause serious diseases or which lessen the sum total of the vital forces and increase the susceptibility to infection. Yet, in lack of sufficient biological study of the question of self-purification of polluted sources of water-supply, the extensive and valuable reports of chemical examinations of numerous streams are very interesting and instructive.

Quite contradictory in their conclusions to almost all others, the eminent investigators engaged on the work done by the famous English Commission, in the years following 1868, asserted that no river, even in a course of more than 100 miles, became purified after pollution by organic matter. In all other countries the opinions are, and generally have been, that after flowing a number of miles from the place where sewage has entered, the river has chemically purified itself of at least a portion of the organic matters introduced. Thus the chemists connected with the investigation of the Seine waters found* that this river, after becoming very foul from receiving the sewage of Paris, purified itself in a flow of from 109 to 150 kilometers, so as to have returned to the same chemical quality that it had before reaching Paris. Of the numerous German presentations of similar facts that of Hulwa† is, like the repeated examination of the Isar at and below Munich, still more convincing. Hulwa found that the Oder, after receiving the sewage of Breslau, had completely purified itself chemically in a flow of 32 kilometers (or less than 20 miles). In this country the determinations of the late Prof. Wm. R. Nichols‡ made him conclude that various rivers of Massachusetts

* *Vierteljahrschrift für öff. Gesundheitspflege*, ix, 434. Durand-Claye: Assainissement de la Seine, Paris, 1885.

† Ergänzungshefte zum *Centralblatt* für allg. Gesundheitspflege, i, 68.

‡ Mass. State Board of Health Report, 1875.

went through a similar process. Very interesting in this regard are Long's* results, as he tested the changes in dilute sewage flowing from Chicago for miles down a canal. The element of considerable constant or irregular dilution is thus omitted till the Illinois River is reached. The oxidizing process causes the water to become much purer at Ottawa, after 80 miles of flow, and it is still purer at Peoria, 150 miles from Chicago. The most notable improvement Long found to be with respect to free ammonia, and the process was decidedly more active in summer than in winter.

Stagnant water and that standing in vessels, require much longer time than moving water to have a definite degree of oxidation take place in the organic substances present. Most chemists have been led to attribute a very great influence in this respect to the numerous bacteria which are found to be present in all sewage-contaminated waters. That the "nitrifying" varieties of these accomplish the work of oxygenation was first declared by A. Müller.† Emich‡ supported this theory by experiments in which he found that water purified itself chemically if many bacteria were present; but the same water sterilized by heating and kept germ-free did not improve chemically until, from exposure to the air, other bacteria had entered. Direct oxidization by the oxygen of the air did not take place, and the action of ozone and peroxide of hydrogen was less potent than that induced by bacterial activity. Heræus‖ studied the question and found that bacteria differed greatly in their activity in this direction. He got no oxidation with any of the few river and earth varieties that he tested. In England and in Massachusetts recent experiments furnish additional corroboration of this theory of the important function of nitrifying bacteria.§

Biological investigations into the self-purification of rivers have been very scanty and incomplete. Frank,¶ Prausnitz,** and Uffelmann,†† examining, respectively, the Spree, the Isar, and the Nebel, found that the number of bacteria present before the accession of the city sewage had increased with the addition of this polluting fluid. Within a dozen

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* *American Chemical Journal*, x, 26. London *Chemical News*, June 29, 1888.

† König, Berlin, 1887, page 99.

‡ *Monatshefte für Chemie*, vi, 77–94. *Chemisches Centralblatt*, 1885, 333.

‖ *Zeitschrift für Hygiene*, i, 193 and 213.

§ P. F. Frankland: *Journal of the Chemical Society*, 1888, No. 53, page 373. Massachusetts State Board of Health Report for 1888, supplement.

¶ *Zeitschrift für Hygiene*, iii, 355. ** München, 1890. †† *Vierteljahrschrift für öff. Gesundheitspflege*, xxii, 377.

miles or so of the place of the introduction of sewage, the water, even if biologically inferior, seemed usually not much worse than might have been the case if no city filth had contaminated the river. Schlatter* has recently reported that the Limmat usually purified itself bacteriologically to a marked degree within 9 miles after receiving the sewage of Zürich.

These and similarly executed observations are very important, even though the present methods of examination have not reached the degree of perfection (aimed at by Chantemesse, Holz, and others) that shall enable us to cultivate the morbific germs, present in a given example, by means of some ideal medium that at the same time suppresses any or all others, as we may elect. The commoner bacteria are, in general, hardier than the noxious ones and (as in the laboratory, so in nature) tend as a rule, to destroy these harmful ones, or at any rate, prevent their increase. Both kinds are exceedingly alike in many respects, and certain varieties of the harmless ones are very difficult for an expert to differentiate from well-known disease-producing varieties. Considering, therefore, the present status of practical bacteriology and its limitations, it seems a very fair test of the question whether rivers purify themselves from infection introduced, if we compare the numbers of germs found pre ent in the water taken at different points. We can then reason from the figures and facts thus afforded. Hence, I herewith present data from some of the analyses which I have at various times been able to make. All have been done according to Koch's gelatine method, and—what is most important—all the waters have (unless the contrary is mentioned) each been "plated" within a few minutes after taking the samples, in sterilized bottles and with the utmost care, from the body of water. To keep the nutrient gelatine from melting when the prepared plates are exposed to warmth, I use a portable "cool chest," which allows the method to be successfully employed in summer, even amid the high heat of the "Great American Desert."

A swift, foaming mountain brook, that of the Kaaterskill "Clove," was tested at a part where it might have recently received the drainage of several hundred people, and where dilution seemed less conspicuously an obstacle to accuracy than would be expected in many parts of the brook's course. The ground was wet with rain which had fallen within twenty-four hours. Hence, the element of dilution and possibly

* *Zeitschrift für Hygiene*, ix, i, 56.

the entrance of new (surface) bacteria make the figures lack absolute value.

September 11th, 1890:	Bacteria in 1 c.c.
Brook in Catskills (after chance of pollution)	54
Same brook 1½ miles further on (after 300 feet of irregular fall)	49

Situated amid the most rugged and densely-wooded of mountains, Cœur d'Alène Lake supplies the Spokane River, which is tributary to the Columbia River. Pend d'Oreille Lake is in similar wild country, and its effluent stream enters the Columbia River in British America. The former lake was not tested, owing to the greater difficulty and delay involved in getting out from it—an element which could imperil the accuracy of the results. It probably has fewer bacteria than the lake given, which therefore answers here the purpose. The water was plated within five minutes of obtaining the sample 50 feet out in the lake, at a time shortly after a rainfall and in a portion near a small lumber camp.

June 10th, 1890 (clear):	Bacteria in 1 c.c.
River flowing into Pend d'Oreille Lake (rain on previous day)	154
Pend d'Oreille Lake, highest number found*	43
Spokane River, 4 miles above Spokane Falls	69
" " just below city and falls (Spokane)	129
" " 1 mile further down	125
Willamette River, 4 miles above Portland, Oregon	44
Columbia River, 37 miles below Portland and 31 miles below confluence with Willamette	52

The Mississippi affords in places excellent chances to study the question. The changes undergone by the decomposable elements of the vast quantities of logs and wood-refuse that the lumber industries cause to be present here, do not seem to cause nearly so great an increase in the number of bacteria present, as though the organic matter were wholly in the form of that coming from the surface drainage of agricultural districts and many habitations. This I have observed in the Ottawa River of Canada and in other parts of the North.

* This number was above that of the average of Western Lakes. Thus, Union Lake, upon which Seattle verges, averaged in the middle of its surface (June, 1890) only 13 germs per c.c. out of three analyses which I made of its waters.

Above the St. Anthony Falls the Mississippi has already drained a fairly populous portion of its valley. After passing over the falls the water receives sewage, then falls rapidly for a short distance, and in the next 10 miles does not appear to receive much other contamination. The time when the water was taken seemed very favorable for excluding any unusual degree of this, yet in view of the figures I am inclined to suspect some contamination not detected. The fact that the sample from St. Paul stood unplated for an hour may explain the number found. Even a passenger boat crossing up-stream may at times cause a decided increase in the number of bacteria in some parts of the current. This I know to my cost, from having thereby had a series of plates made at Sault Ste. Marie rendered unreliable for the purposes of this paper.

June 8th, 1890 (clear and sunny):	Bacteria in 1 c.c.
Mississippi River, above Minneapolis	620
" " just below Minneapolis	794
" " above St. Paul, 10 miles below former sample; no obvious source of pollution	843

(Last sample kept one hour before plating.)

But for its short flow, the Passaic River furnishes every feature that could be desired for the study of this question. The northernmost tributaries furnish pure water in most parts. Between the junction with the Pequannock and the Great Falls at Paterson (6 or 7 miles) its way is through a rocky valley receiving relatively little drainage. In that distance, and with the Great Falls, the descent is 100 feet. Before the partial obliteration of the Little Falls, recently accomplished for economic agricultural reasons, I endeavored there to determine the influence of the violent agitation upon the number of micro-organisms in the stream before and after such action:

February 13th, 1889 (sunny and cold):	Bacteria in 1 c.c.
Lake Macopin, highest number found	57
Pequannock River (below a hamlet)	361
Passaic River, above Great Falls at Paterson (after draining 855 square miles)	573
Passaic River, below Great Falls in Paterson (near a mill)	1030 ±
Passaic River, below railway bridge (after receiving sewage)	2172
Water from Newark hydrant (supplied from lower Passaic River)	4000 ±

November 5th, 1889 (cloudy and cool):	Bacteria in 1 c.c.
Passaic River, ½ mile above Little Falls	372
" " 10 feet from rocky bank, just above falls	720
" " " " " " " " below "	704
" " Middle of Lincoln's bridge (5 miles down stream)	631
" " just above Great Falls	600 ±
" " just below " "	600 ±
" " Middle of railway bridge (after mingling of sewage)	1934
" " " " " " above Passaic	1907

[± Denotes partial liquefaction of plates such as to prevent absolutely precise determination.]

After leaving the region of Port Jervis the Delaware gradually enlarges, but regularly receives comparatively little objectionable drainage till Easton is reached at the junction of the Lehigh. Here it has mingled with it the more or less recent and diluted refuse of probably more than one hundred thousand people. All the way down to Trenton, over 50 miles further, the drainage is considerable and comes from a large area having many farms and numerous inhabitants. Thirty miles beyond Trenton, Philadelphia takes part of its water from this river after it has flowed from a water-shed supporting over half a million people.* My examination was made at a time when considerable rain had fallen in this valley during the previous three days, and the biological results must be numerically regarded as those of the river when at its worst. Various kinds of micro-organisms were detected in the water, including numerous "earth" and putrefactive bacteria. Among these were "Proteus" forms, which may be ranked among the objectionable varieties, yet† they are probably antagonistic to the germs of typhoid.‡

The Trenton water, said to be from the hydrant, and stored from the river several days previously, taken by me on the same day at the Pennsylvania Railway Station, had only a few hundred bacteria of five distinct harmless varieties. It was quite unlike the river water in character.

April 27th, 1889 (rainy, river swollen):	Bacteria in 1 c.c.
The usually excellent lake above Delaware Water Gap	1230
Delaware River at Water Gap	3400
" " above Easton	4270
Lehigh " " "	4925
" and Delaware mingled four miles below Easton,	10000 ±
Delaware River at Bridge near Trenton water intake,	20340

* See Report of Engineers Hering and Ludlow, Philadelphia Water Department, 1885.

† Hauser: Ueber Fäulnissbakterien, Leipzig, 1885. Bordoni-Uffreduzzi: *Zeitschrift für Hygiene*, iii, 333.

‡ Karlinski: *Archiv für Hygiene*, 1890, 473.

The following were at the same time collected by Philadelphia Health officer, and carefully kept cool till plated by me after four hours or more:

Delaware River, Philadelphia pumping station....	28000 ±
Schuylkill at Roxborough	43750 ±
" at Spring Garden.....	44456 ±

Under these unfavorable conditions, rivers, even in a sparsely settled region where there is little or no farming, may be expected to show an increase in the number of bacteria as the samples are taken further and further down the stream. This I have observed in several of the rivers of this State and elsewhere in the East, as well as in the Yellowstone Valley this summer on the occasion of a rainfall. Then the river at Glendive had more living germs in each cubic centimeter than were found at Billings, which is over 250 miles further up-stream.

The causes of the large proportion of cases of typhoid in Philadelphia, cannot be traced to any single source of infection. The water supply—if indeed the chief cause—may have received the dangerous germs at any place between the pumping-stations (in sewage-polluted tidal waters) and more or less remote tributaries. It is very difficult to prove that contagion can be carried many miles down a river, and many deny the possibility of this occurring. Owing to the use of contaminated milk by a number of families in Port Jervis, on the upper Delaware, a town of less than 10 000 inhabitants, the place had a slight epidemic of typhoid fever from October 1st, 1883, till the end of the year. No increase in the number of deaths from that disease in Philadelphia was recorded until January, 1884, when the total amounted to almost double the average for the same month during the preceding five years. From these facts one should not infer that the increase of the disease in Philadelphia was caused by the bacteria which had survived the 100 mile passage down the river, especially as in Trenton (which also takes water from the Delaware) there was, as I learn through the kindness of Dr. Ezra M. Hunt, no increase of this disease noted at the time. Still it seems highly probable that the health of the city would be improved, if all its water used for domestic purposes came from a remote location on this fine river, and were then conducted for many miles through an aqueduct. The deeper such aqueduct and its reservoir, the cooler would the water be in summer; and the more moderately cool pure water is, the more wholesome it is for the masses of a city's population.

From the above-given observations it can perhaps be inferred, that

under the most favorable conditions, river water tends to a certain degree to purify itself of infective and other bacteria introduced. Yet the evidence thereby afforded does not seem strong enough to wholly justify such a conclusion. So long as fresh contaminations are constantly entering, the purificative tendency is virtually inoperative. Successive pollutions cause river water to become inferior in quality, as it is tested further down stream, and until after any considerable pollutions have for some distance ceased to enter. The liability to error, owing to unrecognized (and not easily appreciable) contamination of the waters, lessens the value of any tests made with our rivers. Hence, for the purpose of definitively resolving a portion at least of the problem, I have had recourse to a series of biological analyses of the Croton water in different parts of its flow through the magnificent aqueduct which for nearly half a century has so well served this city.* By reason of its superficial passage and of the configuration of the country, the old Croton aqueduct follows a more devious course than the new one. Therefore, and because of the thorough aërification, the old aqueduct (although dark throughout) is (for our purpose) much like an ideal stream, and is admirably adapted for testing the question at issue. The samples were collected at such intervals as corresponded with the flow of the current, which averaged a rate of a little more than 2½ miles an hour. Plates were prepared from the water as soon as it had been taken by means of the usual sterilized bottles.

Water of Old Croton Aqueduct.	Miles from Central Park.	Bacteria per Cubic Centimeter.				
		Dec. 25th, 1889, clear, 39° Fahr.	Feb. 27th, 1890, clear, 37° Fahr.	Apl. 3d, 1890, drizzly, 40° Fahr.	Sep. 30th, 1890, clear, 60° Fahr.	Oct. 11th, 1890, some hours after rain, 58° Fahr.
Sleepy Hollow, Tarrytown	27	....	....	420	372	....
Dobbs Ferry	22	....	453	....	....	....
Yonkers	17	....	283	....	....	....
Van Cortlandt	12	....	292	....	207	405
Bronx inflow, adding $\frac{1}{12}$ or less to volume of stream	....	....	[227]	....	....	....
High Bridge	6	347	266	413	240	377
Central Park (inlet to reservoir)	0	285	175	407	199	302
West side, hydrant	....	229	137	394	215	248
New aqueduct (slight temporary flow)	....	....	....	....	183	....
Surface of reservoir	....	....	....	....	72	143
1 foot from bottom of reservoir [35 feet deep]	....	...	....	....	487±	†
3½ feet " " " " "	....	....	....	....	368±	†

* I wish to indicate my appreciation of the courtesy of the Chief Engineer and his assistants.

† Hydrophore worked defectively, and, that day, the level of the reservoir water was 7 feet lower.

These results must be interpreted as indicating, that under the best sanitary conditions, the number of germs of bacteria present in a flowing water usually tends to become less after a course of a few miles, provided that no new ones have taken the place of those that have lost their vitality. After a single pollution by sewage-matter, introducing bacteria of various kinds, the bacterial contents of a given volume of a flowing water tend to gradually lessen in number. So, the question arises: How is this decrease produced? As factors possibly acting to bring about this result we may consider—dilution, sedimentation (subsidence), concussion, chemical influences (including oxidation), light, heat or cold, and the previously mentioned and admitted antagonistic action of other micro-organisms.

Dilution of the water in which they are living does not kill bacteria; and the fewer existing in a given water, the longer can any harmful ones present probably resist the antagonistic activity of the others. Dilution by a better water lessens, of course, the number previously existing in a given volume. Inasmuch as the little that is known on the subject leads us to infer, that of disease-producing kinds, a considerable number of individual bacteria must reach the vulnerable part of the invaded animal organism before they affect the health, if they do so at all; we may believe that a lessening of the number of harmful bacteria by means of dilution renders water less unfit for drinking, yet does not make it absolutely wholesome, even though causing it to appear relatively so. In the Niagara River, for instance, this element is very important. Having there several times been thwarted by rains and by other causes when starting out to analyze the waters, I received and examined a series of carefully expressed samples which, if they had yielded the same results to examination begun on the river bank immediately after they were removed from the river, would have allowed the inference that the river-water, contaminated by the sewage of Buffalo, became biologically as well as chemically much purer at Tonawanda, 11 miles lower down towards the cataract. Unfortunately the complete immediate examination could not be made. There, as in most rivers, the purification is in great part effected by dilution. In the river water above the falls very many hundred bacteria were found after a rainfall, which there, as in other places, can by surface washing bring in noxious elements.*

* Fluegge (*Hygiene*, 1889, 193) states that *bacillus Typhoid* has been isolated from earth of a field with which typhoid dejecta had "not long before" been mixed. We know that these and other bacteria can, under certain circumstances, live for months in dejecta.

See Grancher et Deschamps: *Archives de médicine* exp., 1889, I, 33.

Uffelmann: *Centralblatt für Bakteriologie*, etc., V, No. 15.

From various experiments* it is known that particles settling in water carry down a notable proportion of the bacteria present. The chemical agents which are at times employed, by uniting with the organic matter present, effect much more than the merely mechanically-acting, weighty particles. Like several other investigators, I have at times during the last two years endeavored to determine whether, in vessels of clear water from 10 to 20 inches deep (also twice in tanks 10 feet deep), bacteria settled to the bottom. The results have been neither uniform nor decisive, yet they seemed to manifest in general a slight tendency to subsidence. In laboratory tests the problem is rendered complex by the jarring of the building, the amount of air and light present, the variations of temperature, and other artificial influences unlike those operative in large bodies of water. The few observations made to test lakes, as by Fol and Dunant at Geneva Lake, Cramer at Zurich Lake, and Prausnitz at Starnberger Lake, do not indicate any great degree of subsidence. Of large bodies of water I have found:

August 28th, 1890:	Bacteria in 1 c.c.
Saratoga Lake, central part, surface	56
" " " " 13 feet down	54
" " 1 foot above bottom, 32 feet deep	163

The few tests here given of the water in the Central Park reservoir, permit the inference that there is there some subsidence of bacteria. Not to consider the larger number found at the bottom (as in only one instance did the apparatus work perfectly), there were considerably fewer on the surface of the middle of this large body of water, than entered through the aqueduct.

Very interesting in this regard are the results attained by G. Frank,† who found that the hundreds of thousands of bacteria regularly detected in the Spree River water, after it had received the sewage of Berlin, continued undiminished till after this foul water had passed into the Havel—a river that then for some miles flowed sluggishly through a series of broad expansions. After a course there of not much over 8 miles, it was usually found that the water taken lower down (from Sacrow) had only a few thousand germs. As this diminution was, for chemical reasons, not to be explained by assuming an inflow of ground-water, it could be attributed to nothing but a subsidence of the

* Kruger: *Zeitschrift für Hygiene*, viii, 109.

† *Zeitschrift für Hygiene*, iii, 355.

micro-organisms in the lake-like widenings of the slow river, perhaps influenced by the abundant organic particles present. The government health office,* testing similarly the city sewage poured over a large area at the experimental station, found a marked diminution of the bacteria present. There many settled in the still water before it flowed over into the Rummelsburg Lake.

Concussion and movement of the water, I have not found to be followed by any considerable and immediate lessening of the number of bacteria, even in waterfalls† or where powerful pumps force it under great pressure. That harmful bacteria present can, notwithstanding vigorous concussion, produce fatal infection, is obvious from the causation of an outbreak of Asiatic cholera at Southampton, in 1866, resulting in 107 deaths. It was traced by Parkes to the dispersion of infected sewage through the air, by the unusual method of the bursting of many bubbles after the fluid had been churned up by powerful pumping, and in a frothy condition driven along an open channel.‡

That sunlight, as also diffused light, exercises an inhibitory influence upon the vitality of micro-organisms, has been a somewhat prevalent belief since the first report of Downes and Blunt,‖ which incited Tyndall§ and various following investigators. Raum¶ gives a list of many of these. A few, like Engelmann,** state their views that this influence does not arrest microbial growth and movement. The majority, like Janowski,†† consider that light, even in a diffused form, restricts the development and activity of bacteria. In deep waters this factor is of little consequence.

The even temperatures maintained in great bodies of water during the warmer portions of the year, are favorable to bacterial life. The combination of moisture and great warmth, as in the Delta of the Ganges, is considered a potent factor in maintaining the germs of cholera so constantly vigorous that there the disease is always endemic. Cold does not destroy all bacteria, although a certain number succumb to extreme

* Jurisch, Berlin, 1890, page 79.

† Schmelck (*Centralbl für Bakt. und Paras.*, July, 1890, page 102), testing Scandinavian waters, found many bacteria in the ice formed from the spray of a waterfall. Here oxygenation, cold, light and the effects of concussion had all been operative.

‡ Frankland: Proceedings of the Royal Society of London, xxxv, 542.

‖ *Ibid*, xxvi.

§ *Ibid*, xxviii.

¶ *Zeitschrift für Hygiene*, vi, 313.

** Pflüger's Archiv, Bd., xlii.

†† *Centralblatt für Bakteriologie und Parasitenkunde*, August 1st, 1890.

cold. Congelation of the water in which they are living seems relatively favorable to a portion of the pernicious microbes present.* In many serious epidemics it has been observed that in ice and snow the infection of typhoid was kept active for months.

Some chemical waste from manufacturing establishments has a destructive effect upon these low organisms; but such vague and irregular means can itself only be called a pollution of the streams, and is highly undesirable. The typhoid fever epidemic of 1889, at Wilkesbarre, Pa., caused it to appear that the bacilli of that disease were probably unaffected by the commingling of coal-mine water (containing free sulphuric acid and ferric sulphate) with the Susquehanna River water, before this was taken by the water-works of the city.† When intelligently employed in suitable proportions, chemicals render foul water much purer. As a conspicuous instance of this I need only mention the city arrangements at Wiesbaden, by which the sewage is treated with quicklime. It thus becomes odorless fertilizer, and clear water flowing toward the Rhine. Dr. A. Pfeiffer,‡ unlike Fraenkel and others, asserts that, even after this thorough treatment of the sewage, from one-fourth to one-third of the bacterial germs remain alive in the water! If this be so, no acids or bases present in ordinary water are of any disinfectant value. Certainly the small amount of carbonic acid found in streams can devitalize no bacteria. Hochstetter|| and Fraenkel§ found that by the action of this agent only a few varieties were markedly affected, and that nearly all the harmful ones could live in carbonated waters for days. My own observations have been to the same effect.¶

The presence of a small quantity of mineral salts, as in the various mineral waters, has no notable influence upon the number of bacteria present. In all kinds of bottled waters from all parts of the globe living bacteria may be found, unless these waters have passed through a sterilizing process. Of the numerous waters flowing from the well-known springs in the Saratoga Valley, I have found that some were wholly sterile, while neighboring ones of like saline ingredients had hundreds

* Prudden: *Med. Record*, March 26, 1887. Bordoni-Uffreduzzi: *Centralbl. für Bakt.*, 1887. Fränkel: *Zeitchr. für Hygiene*, i, 2, 302.

† Breneman, *Jour. of the Am. Chem. Soc.*, xii, No. 1.

‡ Deutsche *Vierteljahrschrift für offentliche Gesundheitspflege*, xx, 55.

|| Arbeiten aus dem königlichen Gesundheitsamte, Band ii.

§ *Zeitschrift für Hygiene*, v, 333.

¶ *New York Medical Record*, xxvii, 680.

of living bacteria in each cubic centimeter, the determinations being made immediately after the water to be tested had issued from the ground.

Oxygen is everywhere present in the atmosphere in such abundance that, even in city streets, its proportion does not fluctuate more than ½ of 1 per cent. from the normal 78.3 per cent. contained in the purest air. Of this atmospheric air, somewhat less than 2 per cent. of the volume of a mass of water is taken by the water. This fact is the foundation for a satisfactory explanation of a great part of the actual lessening of the number of bacteria in a flowing stream. They may be assumed to perish, in the active exercise of their function of causing the organic matter to oxidize. When this impurity is in the form of the organic matter occurring in sewage, the process of oxidation is a much more active one than with the *humin* substances found more prominent in purer river waters. It can hardly be claimed that ozone is ever present in these waters in sufficient quantity* to act as a disinfectant. The same may be said of peroxide of hydrogen which, in the laboratory, as we may believe from the experiments of Altehöfer† and others, destroys *B. typhoid* and all other bacteria exposed for twenty-four hours to a 1.1000 solution of this in water.

We lack more precise knowledge than has been indicated by the references already made in this paper, concerning the antagonistic action of the various putrefactive and other bacteria upon the pernicious varieties. All that can be said is, that at least some of the various disease-producing kinds perish, or fail to increase, when the ordinarily-occurring varieties are abundantly present. Yet some harmful species may thrive, despite the presence and activity of common bacteria which suppress the less hardy of the harmful ones.

Summary and Corollaries.—While our knowledge of the causation and intimate processes of disease is at best very limited, and while telluric and other conditions exercise, upon our states of health and illness, influences not as yet comprehended, recent progress in biological science has caused us to know more and more about the origin and extension of various infectious disorders. In view of bacteriological explanations, we cannot doubt the potency of polluted water in inducing the

* Kowalkowsky, *Zeitschrift für Hygiene*, ix, 1, page 89.

† Altehöfer: *Centralblatt für Bakteriologie und Parasitenkunde*, July 25th, 1890, page 136.—Van Hettinga Tromp: Wasserstoffsuperoxide ter Desinfectie van Drinkwater, 1887.—Uffelmann: Jahresbericht, 1888, 47.

diffusion of some infections, and notably of typhoid fever. Like other harmful germs, the characteristic bacilli of this disease can live for days in water whose gross appearance is that of purity, and in which only the biologist can detect the impurity, although the other micro-organisms, such as are nearly always to be found in natural waters, tend to destroy the pernicious varieties.

There exists in all streams a capacity for at least partial self-purification after sewage or other pollution has entered. Biologically, this is manifested by a lessening of the number of bacteria present after several miles of flow, in case no fresh accession of inferior water occur. The pernicious varieties probably lose their harmful character, or when not excessively abundant are so diffused throughout as to be virtually harmless. Dilution seems the main factor in inducing this improvement, but oxidizing processes are of considerable importance in purifying waters. In rivers with very slow current, or in lakes, probably some bacteria settle. They unquestionably do so when the state of the water is such as to induce sedimentation. The application of this principle has produced beneficial results in the water systems of certain cities. "Antagonisms" among bacteria, shorten the life of disease-producing germs in waters where other (presumably harmless) kinds abound.

The excellent water supplied to New York is somewhat improved by the long flow through its aqueduct; yet too great care cannot be taken to keep the Croton watershed as free as possible from all habitations and industries. Only by vigilant and intelligent efforts can lasting and constant purity of the supply be maintained. Especially on summer days and during the time of high dry winds would it be advisable to more assiduously moisten the dusty and much frequented walks and roads about the Central Park Reservoir, as the deposit of much undesirable dust and accompanying bacteria in the water (shortly before its distribution throughout the city) could thereby be prevented.*

It is more economical and much safer to prevent contamination, than it is to use filters when the water has become dangerous. Large filters, when very carefully managed, effect a great improvement in

* When moistened, bacteria and the dust which is the usual means of carrying them through the air, remain upon the ground where they may have fallen. Unclean dust can be carried very far; but I will here only intimate that the excessive filth of our streets will be sufficiently remedied only when our greater and lesser lawgivers are made to realize the importance of cleanliness in every sense of the ill-understood word. Unclean streets and dwellings among the poor can cause disease among the opulent. The filthiness of individuals can endanger the health of the many.

inferior waters;* but they do not prevent all disease germs from passing through.†

It would be a most prudential act for the State to restrict the present devastation of its fine woodlands, and we should encourage the planting of at least one tree for every one hewn down. Forests afford a very valuable means of water-storage at the fountain-heads of our streams, and aid greatly to preserve the desired constancy of flow.

Inasmuch as impure water probably causes disease oftener than we can demonstrate, and as there is, unfortunately, an immense body of irrefutable proof of its frequent harmfulness, all suspected water—and this especially at time of an epidemic—should, like all other foods, be cooked. Concerning such liquid foods as water and milk, it may be said that a very brief boiling,‡ makes them free from the infective property which they in an uncooked state might possess.

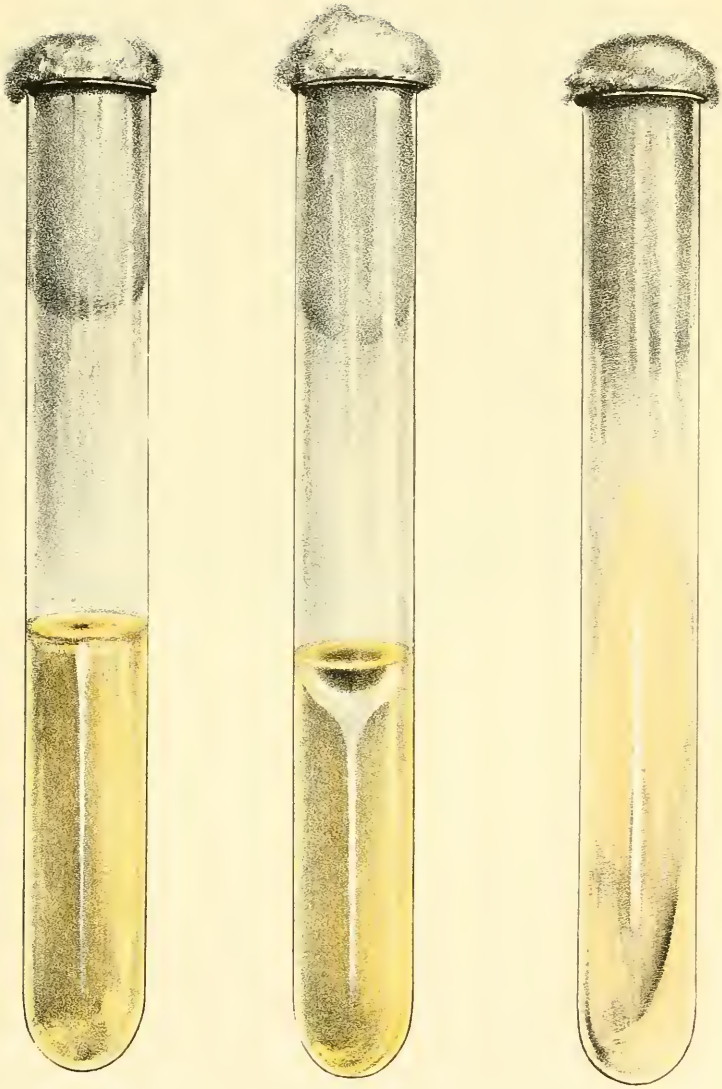
APPENDIX I.

Into test-tubes, such as are shown on Plate IV, we place a very nutritious bouillon rendered solid by the addition of 10 per cent. of gelatine and then steamed long enough to kill any germs which might be living in it. This becomes fluid as the temperature rises above 73 degrees Fahr. If to it in this softened state a few drops of average water be added and the mingled contents of the tube be poured into a shallow glass dish, the mass solidifies after a little while unless kept warm. The individual living bacteria which were in the added water are thus distributed singly throughout the even layer of the solidified nutrient gela ine, and in a few days each of these micro-organisms (perhaps less even than $\frac{1}{25000}$ inch in size, and usually not over $\frac{1}{5000}$ inch in length), has multiplied so enormously that we see in it, and upon the surface, spots varying in size from that of a pin-point, or smaller, to even that of a coin, and composed of many thousands or of millions of individuals. (See Plate V.) These are called "colonies." Their appearance varies greatly, and thereby in part we recognize different species. To study these further and distinguish species, we take a piece of platinum wire 2 inches long and fixed in the end of a glass rod, the whole having been passed through a flame to devitalize anything that might be upon it. We lightly touch the tip of the wire to one of these colonies and then pass the tip over the surface of (or into) various "culture-media" (such as potato, agar, gelatine, etc.), contained in test-tubes and which

* Currier: *Medical News*, April 27th, 1889.

† Fraenkel: *Deutsche Medicinische Wochenschrift*, December 12th, 1889, pages 1023, 1025.

‡ *N. Y. Medical Record*, June 14th, 1890; *N. Y. Medical Journal*, June 21st, 1890.



After 30 hours

After 100 hours

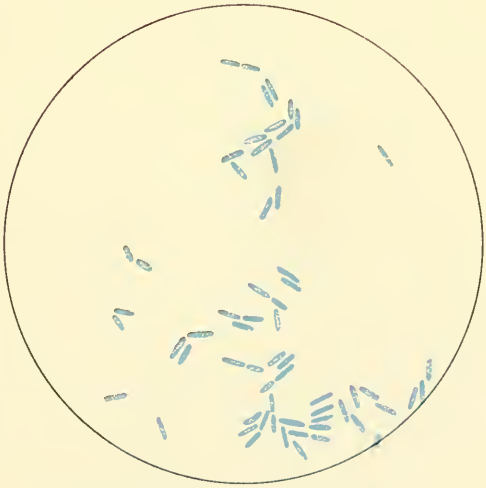
Koch s Cholera Spirilli in gelatine.

Oct. 29th, 1890.
C. G. C.

Typhoid Bacilli
Third day of
growth on Agar.

Oct. 29th, 1890.
C. G. C.

Croton water ⅛ C. C. added to gelatine, and seen on black background Natural size, third day.



Water Bacteria from one of the constantly occurring, whitish-buff, liquefying colonies, colored with methylene-blue and magnified more than 2250 times.
(Zeiss' "Homogene Immersion", 2.0 M. M. aperture, 130 and ocular No. 18.)

have previously been sterilized by moist heat. In a few days the different varieties of bacteria have caused peculiar and distinctive growths to appear. If a minute portion of one of these is spread on glass and viewed through a high power of the microscope, it will be seen that the growths are composed of very many minute bodies which are bacteria. Some bacteria—as, *e. g.*, the variety characteristic of consumption (*Bacillus tuberculosis*) and those which thrive only in the absence of oxygen—have to be studied in other ways, yet this sketch indicates the general principles of the Koch method of determining the number and varieties of water-bacteria present in a given sample.

APPENDIX II.

The Efficacy of Filters and of Other Means Employed to Purify Drinking-Water.

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*A Bacteriological Study.**

By Charles G. Currier, M.D.

Water, even after having been exposed to various chances of contamination, is very generally drunk as it is received from lakes or rivers, wells or springs, tanks or hydrants; and, despite the most disinterested warnings, people are not ready enough to believe that clear, sparkling water may at times be the most harmful of beverages; that it can carry with it, and introduce into the systems of a portion at least of those who drink it, the immediate causes of various impairments of health. Polluted water may be agreeable to the taste and have no visible sediment, yet cause many deaths. Such water the unskilled are slow to suspect, and but for the advance in sanitary science, and the warnings conveyed by those familiar with hygienic studies, pure supplies of drinking-water in cities would be much more of a rarity than they are.

At the Hygienic Congress in Vienna, in 1787, M. Brouardel stated that he knew of over sixty epidemics of typhoid fever which had been induced by the drinking of infected water. From typhoid fever thousands of deaths occur every year; and, although scientific physicians are constantly urging these facts, it seems to be necessary that the danger present itself in the form of an epidemic before the people fully realize the immense harm which may result from impure drinking-water. The epidemic which ravaged Plymouth, in Pennsylvania, four years ago, attracted great attention at the time, but the history of several similar

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* Read before the Section on Public Health of the New York Academy of Medicine, April 5th, 1889.

Condensed from *The Medical News*, April 20th and 27th, 1889, where some of the bibliography can be found.

"visitations" since then, would indicate that the full value of this severe lesson has not been properly appreciated.

Water may be very highly colored, and yet, if freshly collected near its source, show no very large number of bacteria. Such is the case with the best of the peaty "juniper" water which I have examined in various parts of the Dismal Swamp of Carolina and Virginia. Although having a large proportion of organic matter, this water is reputed eminently wholesome, and an inquiry among a portion of those drinking this exclusively, appears to show an unusual degree of immunity from the manifestations of diseases which might be attributed to the effects of improper drinking-water. If harmful bacteria be introduced into it, such water favors their increase, while they would not be so apt to multiply in a very pure water having much less organic matter. Despite the good reputation which this water has had, and its wholesomeness near Lake Drummond, one who has seen the whole length of the canal down to the lower end, from which the supply for vessels is taken, can realize that the water may undergo considerable contamination before it reaches that part. I am sure that the present use (in our navy) of distilled water, kept in proper receptacles, is safer than the employment of the swamp water. On the other hand, the turbidity which is common at this season of the year in the streams furnishing the water supply of many of our cities, is almost always accompanied by a large number of bacteria. The melting snow and the rain, which wash into the streams an increased amount of organic matter, introduce with it other germs (perhaps pernicious), and bring more nutriment than usual to the micro-organisms already in the water.

It is believed that, like most of the varieties of bacteria found in water, the still larger forms of animal and vegetable life, ordinarily existing in lakes and rivers, are not prejudicial to health. It is through the products of the decomposition of many of these, when their life has ceased, that they may become harmful.

Chemistry has long furnished a means of recognizing polluted water, even when it yielded no sediment visible to the unaided eye; and the presence of considerable quantities of chlorides, nitrates and ammonias, determined by the chemical tests, has shown that many a water had more organic impurity than was considered desirable; and, when far below the accepted standard in this respect, such a water is justly condemned. Yet it seems as though enough of the infective element of cholera or typhoid to diffuse an epidemic throughout a community can be added to a drinking-water, and not be detectable by chemical tests. A perusal of the very complete and instructive paper by Professor J. W. Mallet (in the report of the National Board of Health for 1882) shows how widely such determinations may vary, and how unreliable chemical standards may be. We are thereby made to recognize that a close acquaintance with the entire watershed, is of greater value than a mere chemical determination.

The known disease-producing bacteria, however, do not appear to increase in water in which there is not more organic matter than the proportion that chemists of constant and large experience regard as permissible in waters which they pronounce to be of fair quality, although these harmful bacteria, if once introduced there, may long retain their vitality and remain dangerous. In my tests, when I prepared an artificial water, I added the germs directly from a pure culture, unlike Bolton, and like Wolffhügel and Riedel (Arb. aus d. Gesundheitsamte, 1886, i. p. 455), with whose results, however, I cannot so well agree as I can with those of Bolton (Ztsch. f. Hygiene, 1886, i. p. 76). I have in

but two out of many trials, with disease-producing species, found typhoid bacilli to increase in sterile pure water, and then only to the extent of 30 per cent. In the Croton when it was sterilized, I have been able to keep typhoid bacilli alive for only two weeks, and usually not over eight or nine days. I have observed that the greater the variation of temperature it was exposed to, the shorter time did this micro-organism live in water.

Since, as yet, chemistry, when called upon to aid in solving the question of the purity of a water, can at its best only approximately estimate the amount of organic matter present and its state of oxidation, while it fails to inform us whether infective matter be present or not in a given water, it has been hoped that a sure means of recognizing whether a water be in any degree infected was reached, when Koch introduced the bacteriological test. This test, while very definite and conclusive under favorable conditions, has thus far been able to decide absolutely, in only a small portion of cases of disease apparently coming from the use of drinking-water. Yet in those cases where the bacteria characteristic of distinct disease have been detected in the suspected water, the isolation, culture and identification of the disease-producing species, furnish a convincing proof of the great value of the method.

The method employed is a simple one. Usually 1 cubic centimeter of the water to be tested is added to 10 cubic centimeters of nutrient jelly, made by solidifying very nutritious beef tea by the incorporation of one-tenth its weight of gelatine. Everything being done with rigid precautions, the water to be tested is added to the nutrient jelly, which has been softened by being warmed to a little more than 30 degrees centigrade. This is then quickly mixed and poured upon a cooled glass plate, where the fluidified gelatine soon becomes quite solid. Then the germs in the water, being scattered evenly throughout the mass, exercise their functions of rapidly multiplying at the room temperature; and, in the nutritious medium, the minute microscopic individual has perhaps by the third day become a dot as large as a pin-point, or much larger, containing thousands or millions of newly-formed bacteria. These are called "colonies," and vary considerably in appearance, as will be seen by comparing the plates made with various waters. With a glass ruled into centimeter squares the number can be counted or estimated. If a large number of thousands be present, as in waters artificially prepared for tests and in sewage contamination of water, the only way to arrive at an accurate estimate is to employ in the eye-piece of a microscope a micrometer square. After determining the number we isolate and identify the species as in general bacteriological study.

There are many features of the subject which must be omitted in a paper of this scope, for they may not interest all, and I will not linger over the still unsettled question as to the absolute value of mere numbers of ordinary water bacteria in determining the sanitary merits of water.* It is, however, admitted that the fewer the varieties present, the less is the likelihood of sources of contamination affecting the water. In examining a considerable number of samples of water from various sources, I have observed that the less chance of contamination there was, the fewer bacteria have I found in the waters. Thus, fine mountain lakes and springs have never in my experience, unless under very un-

* Gärtner: Correspondenz Bl. d. allg. ärzt. Ver. von Thüringen, 1888; Nos. 2 and 3.
Centralbl. f. Bakt. und Par., iii, 5, p. 161 *et seq.*
Wolffhügel: Arbeiten aus dem Gesundheitsamte, Band i., iii, 5 Heft (1885), p. 546.
Plagge und Proskauer, Ztschr. f. Hygiene, 1887, pp. 470 and 486.

favorable conditions, shown as many as one hundred bacteria in each cubic centimeter, while the same quantity of water, from a river draining thickly peopled valleys, may show more than fifty times as many. While it offers less striking extreme differences than I have seen in the Hudson Valley and elsewhere, the Passaic water-shed may be briefly instanced as illustrating what I have just said. I give it because it is the smallest one near us offering every phase of importance in this connection, and because the subject of a supply to come to New York from that source, has been seriously considered. The best of the upper lakes of this system showed on a pleasant day of the past winter, only fifty-seven germs developing in the nutrient gelatine; the Pequannock and other tributaries into which these lakes flow showed, in the samples collected as nearly at the same time as possible, over three hundred and fifty germs, which number increased as the water was taken further down stream; while at the Passaic Falls, in Paterson, over a thousand were detected in each cubic centimeter. Water from a hydrant in Newark, at the same time, showed nearly four thousand germs of bacteria in each cubic centimeter. The Newark water supply is at present derived from the Passaic, some miles below the place where sewage from Paterson is discharged into the river.

As in chemical, so in bacteriological water examinations, those who have had the broadest experience and who are most careful are best in a position to pronounce an opinion. Apart from any personal equation, there are still limitations to the entire comprehensiveness of the method. I may mention that bacteria are recognized as present in the human body and in its products and changed tissues, which bacteria are never found to live on the gelatine or other water plates. Then, too, a water may be submitted for examination when all the obvious infection has disappeared, or has become exceedingly diluted, and hence a most painstaking test, then fails to reveal the presence of the characteristic micro-organism. The period of incubation, after the infection and before the symptoms are recognized, may in Asiatic cholera occupy the greater part of a week, and in typhoid often lasts for two weeks or more, so that all traces of the harmful bacteria may have left the water before it is suspected. By reason, also, of its likeness to various harmless species, and its tendency to be overwhelmed by other more rapidly developing forms, the "colony" of the disease-producing species may be hard to identify. In this respect typhoid is decidedly more difficult than cholera to recognize in ordinary water.

For those who believe that bacteria of certain kinds living in water, and with this introduced into the alimentary canal, can in many cases induce disease; this test, being so precise and delicate as it is, must appear the best way of determining whether the filters and other means in common use are efficient, or otherwise, in removing the dangerous elements from impure water passed through them—in short, whether they act as "disinfectants" of the water.

As various other agencies are used in conjunction with, or as supplementary to, filtration, it is proper that I here indicate how far they serve to purify drinking-water. One of the most prevalent means directly resorted to for this ostensible purpose, is the admixture of wine (usually red). Adding this to an equal amount of Croton water, I find that a varying proportion of the bacteria are killed, sometimes less than half, even after the mixture has stood for days. The spirituous alcoholic beverages (having from 45 to 68 per cent. of alcohol), mixed with Croton hydrant water in equal parts, cannot be depended upon to kill all the bacteria, especially when "earth" bacteria are present, and a

small percentage of whisky (less than 20 per cent.) has very little effect in this direction. In malt liquors, as lager beer, the prolonged boiling in the brewer's kettle has destroyed the bacteria of the original water, even if they be of the most harmful and resistive species which we meet here. Various kinds, however, if present in vats, kegs and bottles, (because of imperfect cleansing), will live in beer. Almost all the artificial mineral waters that I have examined are made of unsterilized water. Pressure of carbonic acid gas, and contact with it for days, reduces greatly the number of bacteria in a mineral water, yet the typhoid bacillus and others will live for days in seltzer water and similar waters. In New York I have found many bacteria in the few carbonated beverages that I have examined. Peroxide of hydrogen, one part to one thousand of water containing harmful or harmless bacteria, destroys these in twenty-four hours. Yet this is an unstable compound which will not gain much usage.

Of the various acids which it is occasionally safe to employ, chemically pure hydrochloric acid must be used in the strength of at least one-half of one per cent. to destroy all the germs in Croton water to which *B. subtilis*, *B. typhoid* and other bacteria have been added; and may fail to sterilize the water even after hours of standing thus acidulated. Sulphuric acid is more than twice as potent, and usually in the strength of one part to five hundred of water, will render this free from living germs. Sometimes, however, it has to be used still stronger, as it is in a certain extensively advertised nostrum, in which, under a fanciful name, it plays the principal part. Alum, lime and the other chemicals which, by inducing sedimentation of organic and mineral constituents, carry down many of the bacteria in water, do not (as is often believed) insure the annihilation and destruction of organisms present. It is the mechanical action of the film, which the presence of a minute amount of these causes to settle sooner than would otherwise occur upon sand in certain large sand filters, which insures their excellence, and the scarcity of bacteria must here not be attributed to a coarse chemical action. When chemicals are added in sufficient strength to destroy speedily all the bacteria which may be present, the water thus treated cannot be recommended as a beverage.

With the imperfection of all other methods, we have in prolonged boiling a sure disinfectant of any water. I have usually found that maintaining a water at the boiling point for even less than fifteen minutes, sufficed to prevent any of its germs from developing in gelatine, and this even with bad waters from sewage-infected rivers. The process of distillation likewise sterilizes water.

The germs of cholera and typhoid are very sensitive to heat, and boiling heat kills them at once.

That freezing temperatures destroy only a certain proportion of the bacteria which exist in the water from which the ice we use is formed, has been established by, I think, repeated observations. I will simply warn against putting ordinary ice into water which we are to drink, as many kinds of bacteria may be thereby introduced. Ice made of distilled or boiled water is wholesome.

The mechanical separation of impurities is the principal action in all filters, whatever their composition. The amount of oxidation produced by the passage of considerable quantities of water through inconsiderable masses of charcoal, sand or anything else, seems never sufficient to chemically purify an infected water, although the Berlin system of filtration, by large beds of sand skillfully managed, effects a notable improvement in this respect. In some cases the nitrifying bacteria

present appear to produce a noteworthy improvement. This element will be spoken of later on.

Almost all tissues tend to separate visible particles from water which is turbid, or in which a deposit settles. The fact that such matter is retained from the water passed through filters, appeals very strongly to most persons; and the general assumption that such visible matter is dangerous, and that its removal insures the purification of water, seems to explain the extensive use of filters. They are all composed of felt-like matter (filtrum), or of any tissue or substance so woven, composed or arranged, as by its structure to more or less completely arrest the passage of sediment and the floating particles existing in varying amounts in nearly all natural waters. The filters in domestic use may be arranged in two classes. In one class the water runs or is poured into a tank, or other receiver, over or beside some filtering medium, through which the flow is into a receptacle, and from this the water is taken as needed, or is stored as fit for drinking. Those of the second variety are designed to connect with the faucets, and to strain from the water such impurities as it brings through the hydrant.

One of the most widely used varieties is a portable one, which renders water clearer and more agreeable to the eye. It is composed of a cylinder of pressed carbon, 3 inches or less in diameter, and having nearly the same depth, which has from its interior a tube passing through the bottom of the funnel in which it rests, thus requiring all the water passing out of the bottom of the funnel to go first through the mass of carbon. The flow is very sluggish unless use be made of pressure or suction, as, for example, by lengthening the tube taking water out of the filter. This, by hastening the action, impairs the effectiveness so far as purification of the water is concerned. After this has been used for a few days, the retardation is very marked, due to the clogging of the filter by the various matters which form the sediment of the unfiltered water. This necessitates frequent cleansing.

Taking a freshly sterilized carbon filter of this sort and pouring into the funnel Croton water just drawn after considerable has run from the faucet, and then collecting in sterilized test-tubes the first flow from the filter, adding of this (as already explained) one cubic centimeter to ten parts of softened nutrient gelatine, the mingled gelatine and water being poured upon a cool plate, it is seen that, before three days have passed, several colonies have developed. Comparing the number of these with that found from the original Croton water plated just after being drawn, we find that at least from 5 to 8 per cent. of the bacteria pass through the filter and develop. The percentage rises as more and more water flows through. From fourteen trials made with simple Croton water, I found that through a carbon filter, freshly sterilized and the introduction of germs from the air and other sources of contamination being guarded against, the first flow showed only a small percentage of the bacteria found in the original water used. Then I continued the use of the same filter without resterilizing it, and endeavored in every way to have the conditions under which it was tested as much as possible like those which would exist in domestic use, and the supply of water in the funnel was allowed to become exhausted at times, as usually during the night. In this filter thus used, the number of bacteria in the water passing through is, on the second day and thereafter, much larger than in the water taken after being poured into the funnel and before it has percolated through the carbon block. This excess, when large, seems to bear an inverse ratio to the volume of the flow.

It is a familiar fact that, if fresh hydrant water in a flask covered with cotton (to prevent the entrance of bacteria from the air) be allowed to stand for a day at the temperature of the laboratory, the original bacteria in the water may be found to have increased considerably. So, as a collateral test, after water had been poured into the filter and before it had passed through the carbon, I have taken some of this original water and allowed it to stand in test-tubes and flasks, both stoppered and open, by the side of the filter similarly protected from the entrance of germs from the air, and exposed to the same variations of temperature.

This water, examined at the same time with that coming out of the filter, showed that the bacteria appear to multiply much more rapidly in the substance of the filter than outside in separate flasks, kept at the varying temperature of the laboratory, as it then was. The water poured in rarely contained as many as 225 bacteria in each c.c., and yet in from one to three days from the time when the freshly sterilized filter had begun to be used, the water after passing through the carbon showed several thousand in every case, and at times more than 25 000 bacteria in each c.c.

All sorts of bacteria appeared to pass through, and not alone water species. The bacillus of typhoid fever will not only pass through, but in two of my trials I found that it had increased. For such special tests I used sterilized Croton water, into which bacteria were introduced from pure cultures. For artificial typhoid water, the bacillus of typhoid was added from agar and potato cultures. Harmful bacteria can pass through such filters, can possibly increase in them under certain favoring conditions, and from parallel tests, seem to retain their vitality longer when in the substance of the filter than when in a glass vessel beside it.

Clean sand fairly represents the granular masses of filtering material, and has all the advantages of powdered charcoal and magnesia as generally used for filtering considerable quantities of water, while it is more readily cleansed of the accumulated organic matter, and, unlike spongy iron, adds nothing objectionable. Unless, as in the case of the large Berlin filters and others acting similarly, rendered more effective by overlying silt and organic matter, beds of sand do not prevent the passage of large numbers of bacteria. I have found many bacteria in waters from various artesian wells coming from a deep stratum of sand, though the best ground-waters are very free from these. Through a thin sterilized layer, from 6 inches to 1 foot in depth, of the finest sand procurable from beaches, all the way from 40 per cent. to 95 per cent. of the bacteria in the original water pass, even when the level of the water is never more than 3 inches above the surface of the filtering mass. When a higher pressure is afforded by the water, very few of the bacteria are kept back.

As in nearly all other filters, so through a layer of sand, all kinds of bacteria, harmless or harmful, appear to easily pass. Here, too, they can multiply in the moist sand. Thus I have found the hydrant water, which entered the sand filter with 290 bacteria in each c.c., to come out through the filter (not freshly sterilized before using) with sixty and one hundred times as many as entered. In a gram of sand taken from a filtering bed, I have found more than 10 000 bacteria.

The combination of other substances with sand, as in numerous small and large filters, fails to improve the usefulness of either, except in so far as the elimination of sedimental and other coarser particles is concerned. Sponge is often employed for this purpose, as well as independently, yet it is incapable of separating bacteria from the water strained through it simply, or through sand or other substances used

with it. When a large mass of fine sterilized sponge is closely packed, the first few ounces of hydrant water that pass through may have a very small percentage of bacteria, but the proportion soon increases; while if the sponge-mass be considerable and loosely packed, it may, even in the beginning and under exceedingly slight pressure of water, keep back no more than 15 per cent. of the bacteria of the original water. This freshly sterilized sponge can, at the end of the first day of ordinary use, cause the water then flowing through it to contain ten times as many bacteria as the Croton water poured in. The stronger the pressure, and the more rapid the flow, the lower is the ratio of excess due to increase in the filter over the quantity found in the unfiltered supply, which, of course, was here, as in all other tests, regularly plated at the same time with the filtered water. When the flow is sluggish, and when it stops entirely at times because of all the water supplied having passed through, the sponge substance favors the increase of the bacteria to a greater extent than is the case with sand. The sponge, within twenty-four hours after sterilization, may, under these conditions, cause the water first running through after the intermitting of the flow, to have five hundred times as many bacteria in each cubic centimeter as are found in the water supplied for filtration.

The only way really to cleanse such a filter, is to remove the sponge and boil it. Then the process repeats itself. In a few hours after unsterilized water moistens it, the mass of sponge is again teeming with bacteria. Sponge filters are, so far as I have seen, becoming less popular. It is easily recognized, even by an untrained observer, that the organic matter in sponge can undergo decomposition under the conditions obtaining in ordinary filters. Several of the large filter systems used in manufactories, hotels and other places where large amounts of strained water are used, employ sponge, and the filtered water abounds in bacteria. Filter paper, as used in laboratories, is useful in separating precipitates and sedimental particles from water, but at least from 50 to 70 per cent. of the bacteria in Croton hydrant water go through with the water filtered, even if the pressure be exceedingly slight. The paper which I employed in the trials was, of course, carefully selected, and the folding was cautiously done, so as to prevent any break in the substance. Only single sheets were tested.

"Prepared cotton," cleansed as for surgical dressings, and so made absorbent, removes considerably fewer of the impurities of the water than does the filter paper. Two-thirds of the bacteria pass through when the cotton is at its best, freshly sterilized and carefully packed. If enough be used, it will usually render the water clear; but, as it has been lauded as a filter, I ought to add the statement of my observation, that when left moistened with water, as in the intervals of filtering through it, the bacteria of the original water can multiply over one hundred and fifty times, and all kinds can pass through it.

Combinations of the various substances mentioned have hardly any enhanced merit as strainers, and, as far as the bacteria are concerned, the combination seems to add no safeguard. Sand with carbon (bone charcoal) and sponge or cotton, hold back at first a larger percentage than sand would by itself. Yet bacteria pass through in any case, and the increase afterward is greater than in simple sand. This I have seen in various filters.

In well-known establishments of New York, where immense quantities of artificial waters are prepared every week, all the water used in their preparation is supposed to flow through a layer of fine sand in the bottom of enormous vats, and from the receptacle into which it then

flows, it passes through a layer of charcoal. These layers are each less than a foot in thickness, and water passes rapidly through. The sediment is thereby removed, but in the examinations which I have been enabled to make, I found that each cubic centimeter of the filtered water had over 2 000 bacteria on each of the plates made, while the Croton taken from the hydrant in the immediate neighborhood averaged never over one-eighth as many.

Asbestos of the best quality, new, freshly sterilized and tightly packed, I have found capable of holding back all bacteria when the pressure of the water was low, and the few that were forced through when the substance was defective, did not seem to multiply so rapidly as in other filter masses. While it, when of the best finish and most tightly compressed, deserves to rank next to the principle employed in porcelain filters, these latter are superior in that they can be regularly furnished of a uniform and definite quality which produces the best results, while it is difficult to keep the best asbestos boards up to their original standard of excellence; and if the surface be large enough to insure an abundant flow of water, flaws are liable to arise, and these let various bacteria through. With asbestos it is the fineness of the surface which the original water encounters that is important, more than the thickness of the layer.

Although wire cloth strains out the coarser particles, its structure does not cause the removal of any of the bacteria from water passing through. Still it has the positive merit of being easily cleansed, and can be heated in an oven or boiled to sterilize it. Furthermore, it does not furnish a filter mass for the bacteria to multiply in, although harmful bacteria can adhere to it, and become dangerous, if it be left uncleaned.

Closely woven cloth (such as thick, dense flannel), when only a slight pressure is exerted by the water, may stop 10 per cent. of the bacteria in the water poured upon it. It is easily cleansed and, if very often changed and boiled before using, serves excellently as a simple strainer, without the disadvantage in this respect of ordinary filters, in whose substance the increase of bacteria may be enormous.

Like porcelain, filters of porous stone (if of the best quality), prevent the passage of bacteria with the water filtered through them just after they have been sterilized. To test porous stone, I employed selected perfect specimens of a popular filter which very satisfactorily clears all turbidity from as bad a water as that of the Hudson River, at its worst. In these, the stone layer was cemented into a porcelain cylinder, and was about ⅜ths of an inch in thickness. The pressure was never more than that of 10 or 11 inches of water, and, at the fastest, less than ¾ths of a liter passed through in an hour. As the sediment of the water settled upon the surface of the stone, the flow became much slower. During twenty-six trials of this kind of filter, it had previously been sterilized ten times by exposure to moist or dry heat, or to both, for several hours. In every one of these ten cases the various waters poured into the receptacle above the porous stone for the first time after sterilization, flowed through germ-free; that is, the stone was permeable for water, but at first allowed no bacteria to pass through, and the plates of gelatine developed not a single colony from the usual cubic centimeter of the filtered water. After some hours of use, a few bacteria had insinuated themselves into the stone or were drawn through with the water. Within twenty-four hours the water flowing through and collected in sterilized receptacles contained many bacteria, which numbered regularly from seven to fourteen times as many as were in

the original hydrant water supplied during these trials. After several days, the number of bacteria had so multiplied in the stone, that the first water running through after the stone had remained for several hours without any flow through it, (as happens constantly over-night in domestic use), showed in each cubic centimeter of this filtered water over one hundred times as many as the average water poured in for filtration. To further test these filters, I have used artificial waters made by adding bacteria of all shapes and characters (from pure cultures) to Croton water sterilized by boiling. These various kinds can get through, but the disease-producing and spiral forms usually died out in large numbers before any could pass. From Croton water, the most marked by its predominance in the filtered product, was a short, mobile bacillus, which was unlike the two varieties first forced through the porcelain in my experiments.

Allied to the porous stone filters, are those of porous porcelain prepared in this country. Porcelain baked at the same low temperature as the porous cups used in electric batteries is, in its efficacy, very much like the stone just described. Under a low pressure, water passing through this substance during one or two days can become completely sterilized, which is a result superior to that got from the stone filters. Before much water has passed, the bacteria make their way through and multiply somewhat on the passage. This material, as I have thus far found it, of American manufacture, is therefore imperfect, yet it is superior to rebaked porcelain, in the single important respect that it is not brittle, while the rebaked porcelain cylinders of the Chamberland-Pasteur filters are quite fragile.

It has for some time been known that fluids can be rendered germ-free for laboratory use, by being passed through solidified plaster of paris (best prepared with incorporation of asbestos shreds). These filters, however, lack permanency, and cause the objectionable sulphate of lime to be present in the filtrate.

Recognizing the defects of other substances, Pasteur and Chamberland called attention to their filtering cylinders, in which the important element is unglazed, rebaked porcelain. Originally employed to facilitate "cold sterilization" of fluid culture media, the fact that water went through the porcelain without carrying any bacteria with it, has caused attempts to popularize its use. Inasmuch as some bacteriologists on both sides of the Atlantic had reported that this filter prevented the passage of bacteria, I was careful to use only selected cylinders without flaws, and did not omit any precaution to prevent the introduction of contaminations.

The most satisfactory way of using this for testing was to employ the single porcelain cylinder, within the usual casing, attached to a hydrant system and with a pressure of water varying from 6 to 15 pounds. Even with the highest New York hydrant pressure the flow is only drop by drop. It can be used to siphon water out of a jar, and in this way it works nearly as rapidly as when attached to the hydrant, in the basement of a house, in the center of this city. By a porcelain cross-tube sold in Paris, two or more cylinders can be siphoning at the same time into the same tube. To avoid risk of contamination, I used for siphoning a single cylinder, to which a bent glass tube was attached by a tightly fitting piece of rubber pipe, all parts having been sterilized, as well as the water by which the flow of the siphon was started. I got germ-free results regularly by this means in seven trials with two cylinders used separately; but, in order to insure this, all the precautions mentioned are necessary, as, in the water siphoned in domestic use of

these cylinders, bacteria of various sorts are found, yet they are possibly contaminations due to the inherent defects of all such joints as are used. So I have devoted more time to testing these when directly connecting with the hydrant, as very slight precautions are needed, in their use with faucets, to eliminate all chances of contamination.

My first thirteen trials of this filter used in this way were under less satisfactory conditions than the fourteenth and those following, as the former were in a laboratory where the available water came under not much more than 20 feet pressure from a tank, and I was not able so well to control the constancy of this pressure as I was during the later trials. My first sixteen tests of various ones of these cylinders gave sterile water. Then, attached to a basement faucet, with a direct flow from the hydrant under a pressure never exceeding 15 pounds, (except that on Sunday nights it was for a few hours 3 pounds higher), the filter, after several days of intermitting use, gave over 3 500 bacteria in each cubic centimeter, and all the water examined (two samples per day) for four days, showed an increasing number of bacteria.

On the third and fourth days after the first passage of bacteria through the porcelain wall of the cylinder, the number in each cubic centimeter varied above and below 400 000. The filter was then sterilized by steaming for five hours, as was also done between the second and third series of tests. These tests bore out the results of the former observation.

That these results show that average specimens of this substance have the inherent defect of all filtering material, though in a much less degree than all others, seems to me unquestionable. That the bacteria did not get through owing to some defect in the particular filters which I used, is evident from the fact that the cylinders employed (and which were selected by me in Paris as perfect), through which the bacteria passed, are still free from any appearance of a flaw which could explain the passage of these micro-organisms. The same filter which (first of those used in my tests) allowed bacteria to pass through, has repeatedly filtered water free from all bacteria for a few days, after each of the several sterilizations which it has since undergone.*

In three following series of trials of this identical cylinder, bacteria have gone through its walls in from three to four days after each sterilization. They have also gone through a second perfect cylinder with which I experimented. That the bacteria were not introduced by careless manipulation is evident by reason of their number, and because of the fact that, after the filter was sterilized, they were found in each case at a particular phase of each series of tests with the intermittent pressure, which only for a few hours once a week was as high as 18 pounds, and was usually as low as 11. At the beginning of each series of tests the filter was sterilized.

The bacteria were not splashed in from the sink below, for, in the first place, all splashing failed to carry in any, as revealed by testing the water filtered after such experimental attempts to throw water in, and none had ever multiplied inside or even remained there during my first thirteen tests, when there was much splashing in the common sink. During my later trials there was no chance of such contamination.

To answer fully in advance any such objection, I will state that after I got the enormous number of over 400 000 in each c.c. flowing through the porcelain, and had sterilized the cylinder, water was allowed to flow

* My results have later been corroborated by experiments made in Koch's laboratory, in Berlin. Kubler, *Zeitschrift für Hygiene*, viii, 48 (1890).

through it and plated, but was sterile in that no bacterial colonies developed. Then, while the filter was in action, I introduced, with a sterile needle, (from below through the aperture into the inside of the cylinder), and, touching the needle to various parts of the surface, deposited over it peculiar bacteria from a pure culture, derived in the winter of 1888–89 from the water of one of the northern lakes, which I examined during my investigations as biologist for the Syracuse Water Commission. The colonies of this bacillus, when grown on gelatine plates, have a peculiar odor, a distinctive green color, and other characteristics which clearly differentiate them from any bacteria ever found in the Croton water. The water flowing out all the while, or rather dropping out, was, three minutes after the introduction of these, collected in sterilized test tubes, and was found to contain 175 000 of these peculiar bacilli in each c.c. After seventy-five minutes there were only 14 bacilli in each c.c. of the water then flowing through the porcelain, and two hours later, and during the next day, there were no bacteria of any kind in the water, which again later in the series showed that the Croton bacteria had passed through with it. This proves that the increase in the number of bacteria was not after the water had passed through the substance of the filter.

These facts, together with the extreme fragility of this rebaked porcelain, and the exasperating slowness of the flow, which does not improve on long trial, have caused me to modify the recommendations which I gave among my colleagues and others after my first tests of these filters.

As regards rapidity of flow and non-fragility, a notable improvement over the cylinder form (which I have just spoken of) is afforded by a series of two or more flat plates of porcelain similarly prepared. In the Varrall-Brisse pattern these porcelain plates are backed by carbon plates of the same shape and size, and the filter yields sterile water for a long time under gentle pressure, although I do not consider the carbon an advantage. The further such filters vary from the simplest type, the greater is the likelihood of the introduction of contaminating bacteria into the filtered water.

Of the various forms of filters used upon faucets, I feel bound to warn against those rotating within an outer shell. Whether packed with charcoal, sand or any other material, and even if the water go through the filtering mass and not around it, the filter has the great drawback of various irregularities and depressions on the interior which retain organic matter, and allow bacteria, both harmful and harmless, to increase in it, and maintain their vitality for a longer time than in ordinary filters. This conclusion I am led to by the results of various experiments and observations. In a recent epidemic in a large New England city this form of filter appeared to play an active part in continuing the infection, for cultures, in every respect like those of the germs of typhoid fever, were derived from several of these suspected filters. I have found that the typhoid bacillus lives much longer in the sediment collected from filters than in pure water. At its best, this filter cannot remove the bacteria from water, and they multiply in the charcoal or sand so that, even after several minutes of washing out by the stream flowing from the hydrant, the water coming through this filter may show several times as many as are in the water directly from the hydrant. To avoid waste of time in repetition, I will refer to the facts observed with the sand filter, as the mechanical action of the filtering mass is identical in both.

The sand filter, for attaching to faucets, is perhaps the simplest and

most popular used. It consists of a cylinder of like breadth and length, being not quite 3 inches long. It screws by either end upon ordinary faucets, and its interior is filled with crushed silica or fine sand, kept in place by wire gauze at either end. I have adapted several much larger without securing more satisfactory results. Taking a new one, sterilized throughout, allowing a fair stream of water to flow through it when attached to a faucet, and at the same time taking water directly from the same supply-pipe from the hydrant by means of another faucet by its side, and under the same conditions of pressure and outlet (except that there is no filter upon the second faucet), the water is seen to flow in a free stream nearly as large as from the unobstructed faucet, while the Pasteur filter attached to the same supply-pipe, and with the same pressure, allows the water to come at the rate of only a few drops each minute. Even with a gentle stream through the freshly sterilized sand filter, very few of the bacteria are arrested. With very fine sand in a cylinder holding three times as much as the ordinary one, and a very small stream flowing, I have observed more than 50 per cent. to be retained. This result is seen only in the first use of an absolutely sterilized filter.

Speaking of the tank variety of sand filters, it was shown that moistened sand favored the increase of bacteria brought into it by Croton water which had flowed through. In the sand or other granular contents of these filters attached to hydrants, the same multiplication takes place when the water has for some time ceased flowing, and this increase is at a more rapid rate than in water standing in a clean vessel by the side of the filter. The first flow in the morning, for instance, after the filter has remained unused over night, shows a much larger number of bacteria than the hydrant water then contains. Even after the water has flowed for several minutes for the purpose of washing out the filter, the bacteria are in excess over the number in the original water. After such a filter has had the hydrant stream running through it long enough to wash out all the germs that have resulted from the increase (which complete cleansing is not always producible), the bacteria in the water may appear nearly the same in number as in the hydrant water, varying slightly either above or below. While such filters are worse than useless from a bacteriological point of view, they are good strainers when not clogged by too long use without cleansing. As strainers they are less troublesome than flannel bags (which are as safe as these sand filters for use with suspected water, provided that they are removed at least once a day to be disinfected by boiling). The act of reversing this popular sand filter does not cause the removal of the organic matter upon which the bacteria can be nourished. Only the loose outer portion is thereby removed. Such a sand filter is a safer strainer when never reversible, and it should be cleansed at least once a day when needed at all.

Powdered magnesia and other granular substances used instead of sand in the style of filter just described, have no superiority over the easily cleansed sand.

Asbestos board I have not been able to procure of sufficiently firm, strong and fine surface to resist the passage of bacteria under any considerable pressure from the hydrant brought to bear upon such a surface. The quality of the surface seems the important point. To yield a flow of any degree of rapidity, this surface must be large, and that creates a tendency to break and necessitates a bulky filter, which most people shun. Packed asbestos shreds allow a few bacteria to pass through when the sterilized filtering mass is so dense as to cause the flow to be very slow. In this substance, I have, as already mentioned, not observed

so marked multiplication of bacteria as in the sand, porous and other filters.

Although large bodies of sand fail to prevent the passage of bacteria with the water which percolates through, it is noticed that certain natural filters of this sort render water much freer from bacteria when the water has first to make its way through a layer of silt, and minute particles which have been arrested by fine sand. It is from the application of this principle that the large filter-beds are built which purify the water distributed by hydrants throughout various cities. Taking as a model the very carefully managed filter-beds of Berlin, it is seen that above the base of the filtering tanks is a layer of a foot of stones, gradually becoming smaller in size toward the upper surface, upon which is coarse gravel to the height of a foot more, then upon this a little more than 2 feet of sand, which at the top is as fine as can be procured. Yet the engineer in charge has recently said that apart from its merit of keeping back the finest particles, the finest sand is not necessary. When the filter-bed has been freshly cleansed, as is found necessary for it after being constantly used for a week or so (occasionally several weeks), purified water is slowly backed into the filtering-mass from below, until this water, carrying up all the air with it, has reached the top of the upper layer. Then the ordinary river (or lake) water is made to flow very gently in, to the depth of 1 meter. This is allowed to stand for at least twenty-four hours. The nitrogenous or other particles, confervoid vegetation and whatever else the water contains as sediment, have, with many micro-organisms, then settled upon the upper portion of the fine sand without sinking deeper, and a delicate film is formed, which, with careful inlet and gentle pressure (never to exceed 2 meters of water), retains nearly all the bacteria of the water supplied, and prevents their passage, provided that the flow through is very regular and slow (never more than 3 meters in a day). With similar filters in Zurich it is found that perfect results are had when the flow is more than four times as fast. Nearly all this separation of the bacteria is produced by the sedimental matter retained on the surface of the sand, so that, when the filter slows from clogging, it is found that less than ½ inch of the upper layer of sand need be removed.

While I have not seen as yet the unpublished report of the elaborate experiments made at Lawrence, on the Merrimac River, under the auspices of the Massachusetts Board of Health, I learn that they inculcate the importance of slow, intermittent filtration for purification of water having much organic matter. I learn on the best authority that these results seem to substantiate the familiar theory that nitrifying bacteria are the most important agent in producing this improvement. This, of course, is true as regards sewage poured upon soil.

On sand-filters as used to purify a bad water for city consumption, it seems to me undesirable to accept this theory as, *e. g.*, Drown does, to explain the great diminution which the best filters cause in the number of bacteria. He, in announcing these results, refers for authority to the presentation of this theory by the engineer of the Berlin water-works, Herr Pietke. The latter, however, when associated with an expert practical bacteriologist, as with Fraenkel in his last article on filtration (see *Zeitschrift für Hygiene*, viii, page 22 and following pages), allows most importance to be attached to the maintenance of the overlying film whose mechanical action is the main reliance. In the article by these two writers, it is asserted that if typhoid germs happen to pass through this film (either by proliferation or owing to a flow) the other bacteria cannot be depended upon to arrest these, even if the water flow slowly. They surmise that the considerable number of cases of typhoid in Berlin

during the early part of 1889, probably came from the use of water in which were the peculiar bacteria of this disease, and that these had passed through the filter.

The nitrifying bacteria are important in causing the purification of water, but we, as yet, do not fully understand them. That the felt-like film above the sand of such filters is by far the most important element, is further made probable by the report of Bertschinger (Zurich, 1889), who found that the waters passing through the Zurich sand-filter, became chemically and bacteriologically very pure; yet they flowed through at times faster than at the rate of 36 feet a day, which is very much faster than allowed by the postulates of those who claim that the nitrifying bacteria do most of the work. Still more emphatic are the excellent results where the various proprietary filtering arrangements force water very fast through sand in which, by *e. g.*, hydrate of alumina and silt, a tenacious filtering mass is produced. It is apparently necessary to study each filter-plant by itself, as the conditions of efficient operation seem to vary with the character of the water to be purified.

From the statistics of Wolffhügel, and of Plagge and Proskauer, we learn that the number of bacteria, originally very large in the river Spree, is reduced to a very small percentage in the filtered water, oftentimes a fraction of 1 per cent. I may add that the organic constituents are also decidedly lessened, and that the oxidibility, as tested by the reduction of a standard solution of permanganate of potash, is seen to be regularly lowered one-fourth, and often one-third of the amount shown prior to the filtering. The long arrays of figures given in the reports of the action of these filter-beds show, that with hardly an exception, the ammonia is constantly removed by the process.

In this country the filter-beds, all of which are built upon the same plan as those in Berlin, are less perfect in their action, as the people in charge do not devote sufficient care to sedimentation in the case of those which I am familiar with. Thus, a very carefully planned filter-bed, which filters river-water for one of our cities, allowed, at the time when I examined it, nearly half of the large number of bacteria in the water pumped from the river to pass through. This unsatisfactory result seemed to be due to the fact that too much water was required from the small filter-beds, and hence not enough care could be bestowed upon thoroughness of the filtration.

Of the various large filter systems which I have tested while they were in use in various manufactories and institutions, for which these filters were straining large quantities of water, the only kinds which reduced materially the number of bacteria as found in the hydrant water, were those in which by the addition of a minute proportion of a suitable salt, usually alum (as approved by the general experience of years in many districts), the suspended particles with the organic matter are caused to settle more rapidly, and then these form a deposit upon very fine sand, through which water is forced. From several examinations of a filter of this type, which in every case rendered the water much freer from germs than the original (unfiltered) water, I once found the filtered water wholly sterile, while the (Brooklyn) hydrant water of the neighborhood at the same time showed 397 germs developing from each cubic centimeter. This particular filter was constructed on the principle of Prof. A. R. Leeds, who informs me that the alum was present in the proportion of only 1 part in 100 000 of water. I could not, by the ordinary tests, detect the presence of this salt, and such a small amount can cause no appreciable harm. The alum used is probably decomposed, and its elements taken up by the organic matter and bases

present. As previously stated, the sterilization of the water is here caused, not by chemical but by mechanical action, which rapidly produces these excellent results without any recourse to assuming the activity of bacteria of "nitrifying" kinds. In my tests, the typhoid bacillus of the first agar culture from a recent spleen, was not destroyed by standing for forty-eight hours in a solution of ten times the strength of that employed in these filters, while many other bacteria were alive after standing for forty-eight hours in an alum solution of 1 part to 1 000 of water, which sufficed to destroy the typhoid bacillus in that time.

In the present stage of chemical knowledge, there seems no sufficient evidence that in water, these micro-organisms evolve the organic alkaloids which are considered to be produced when harmful bacteria are introduced into the system, and by their action there cause disease. What the exact nature of the volatile organic constituents carried over in distillation may be, and whether they are in any way deleterious or not, rests for the science of the future to determine. The process of boiling previous to vaporization in the still, must kill all harmful bacteria, and all other bacteria that I have ever encountered, in the original hydrant water from which such water is prepared. The bacteria which I have found in specimens of distilled water, must have been introduced from without after the water was condensed from the still, and before the bottling process was completed, but in this I have never found any other than harmless varieties. Water condensed from various stills of approved patterns I have found sterile. The relatively large amount of free ammonia found in such distilled waters (it being several times greater than any detected in the Croton hydrant water) does not seem to me to be objectionable. The condensed steam produced in distilling, represents a much larger original amount of water than results after the process of vaporization and condensation is completed, and the ammonia may besides come from the air and from other sources.

To those who desire a water freer from alkaline earths than the ordinary "hard" water which they may have to drink, it should be mentioned that the process of heating, in the sterilization by boiling which I so urgently recommend when it is necessary to drink suspected water, drives off free carbonic acid, and so causes the deposition as an insoluble sediment, of the carbonate of lime and other objectionable salts which form the so-called "temporary hardness." The water is thus rendered "softer."

When boiling is resorted to because of actual infection of the water, it should be carefully done. It is best to have the water, perhaps after a preliminary boiling and straining, decanted into bottles, each holding, say, a quart, and these covered with a suitable glass cap, or plugged with cotton, or provided with a clean stopper loosely dropped in, and then the bottles placed in a kettle or cauldron in the absence of a steaming apparatus. This is heated and kept near the boiling point for half an hour. Then the whole is allowed to cool, and the bottles may be placed near ice; but in the water thus carefully prepared it is not advisable to put ordinary ice, for harmful bacteria may retain their vitality in ice longer than in water. Pure water loses all its excellence when unwholesome ice is melted in it. For those to whom the taste of boiled water is unpleasant, weak teas, wine or other savor may be added to mask the absence of the more agreeable taste imparted by the process of aërification (which under ordinary conditions may itself be a means of adding bacteria to the water).

Summary.—Boiling sterilizes water, and within less than five minutes will have killed harmful bacteria of any kind that are liable to occur in water.

Drugs and other agents acting chemically, if used in amounts which are commonly safe, do not sterilize water till after an impracticable lapse of time.

The prolonged heat which water undergoes in the usual process of distillation, destroys all germs which may be in the water undergoing the process.

Ordinary filters, even if satisfactory as strainers, fail to remove all bacteria from drinking-water. So far from lessening the number in the original water, the filtering substance may allow a more rapid multiplication than these micro-organisms would ordinarily undergo in the unfiltered water on standing; and the germs of disease, even if held back by the filtering substance, may be harbored in all filters.

The finer the substance through which the water passes, the lower the pressure and the slower the flow, the more perfect is the action of the filter in holding back the bacteria.

Of all substances thus far furnished for domestic filters, porous rebaked porcelain, carefully selected, I have found to be the best. If thick and strong enough to allow the use of a large surface, and the substance remain perfect (without flaw or break), this may yield a fair flow of clear water, free from all bacteria; yet under our ordinary Croton pressure of one atmosphere or less, this yield is only in rapid drops, unless the apparatus be complex.

To insure the permanency of this action, the filter should be occasionally sterilized throughout, by steaming or by other means; for under prolonged pressure, various kinds of bacteria can go through, and in the copious organic matter collected on the filter some harmful micro-organisms can retain a high degree of vitality for weeks longer than I have ever found them to live in pure water.

Where filtering is really necessary, it is generally best for the community that it be done carefully on a large scale through sand-beds upon which a fine layer of organic and inorganic matter is expressly produced by sedimentation, because of its valuable action in holding back the great majority of the bacteria.

A bad water, filtered, is less desirable than a pure water in its natural state. When, therefore, filtration is employed because of real danger of infection, the filtered water should, as a rule, be furthermore boiled, as the entire absence of sediment and cloudiness does not insure that the bacteria of disease may not have made their way through the filter.

DISCUSSION.

Charles B. Brush, Director Am. Soc. C. E.—Does the pressure in the pipe tend to reduce the vitality of the bacilli?

Dr. Currier.—Not necessarily; it may somewhat.

Mr. Brush.—Do muddy rivers and rivers carrying a large proportion of silt have a tendency to reduce the actual amount of life?

Dr. Currier.—That depends on the composition of the silt.

Mr. Brush.—When silt is removed by settlement from silt-bearing rivers like the Missouri, does this settlement remove the bacteria in water?

Dr. CURRIER.—Such settling may remove some. But sedimentation is most effective when caused by the artificial introduction of lime, as at St. Louis, or by alum, which is used in some large filters. An organic combination is thereby formed which carries down more particles than do settling particles of sand or other heavy particles.

Mr. WM. E. WORTHEN, Past President Am. Soc. C. E. said: Dr. Currier states, "The best deep springs show few or no bacteria; and uncontaminated water flowing directly thence is, unless highly impregnated with minerals, the most wholesome of beverages." It has been my experience that such well-waters develop algæ readily and abundantly when exposed to the air, as in all cold household springs these algæ invariably hang around the barrel, in the well-water supplies of Newton and Waltham, the water supply of Fort Wadsworth, Long Island City and East New York, which last were under my charge. Protecting the reservoirs and springs from air and light has, when tried, invariably stopped their development. The function of these algæ, as generally received, is to supply oxygen to the water in form of solution, and not mechanically. Although algæ are not generally considered dangerous to life, or detrimental to health, they are objectionable to consumers on account of the color given to the water in their life, and the taste and smell by their decease. It has been a question with me whether the water would not be better if the algæ were left to develop and absorb, whilst living, into some higher organisms. I have propounded this question to our member, F. P. Stearns, of the Massachusetts State Board of Health, with the following reply: "I suppose that ground water does contain less oxygen than surface water, although it will acquire it in a very short time on standing. I do not understand that it contains the undeveloped germs, but rather the food upon which the germs of algæ already in the reservoir thrive, and I think it may be a question whether horse sense is to be trusted. With regard to the death rates from a disease like typhoid fever, I believe that during the last eighteen years there have been 10 per cent. more deaths from typhoid fever at Lawrence than at Lowell, and more deaths at each of these places than at most large places in the State. There is one city, however, with an unpolluted water supply, which has had 50 per cent. more deaths from this cause; and the variations between other cities which have equally good water supplies are greater than between Lowell and Lawrence, showing that other causes have a greater effect than the water supply."

Time is a very large element in determining the value of facts and the inductions from them. Dr. Wolcott, in his address as President of the Public Health Association, says: "Unfortunately, man's life is hedged about with many injurious influences, which we do not understand accurately, and which we cannot remove.

"In several cities of Massachusetts, epidemics of scarlet fever, as well as of diphtheria, have been recorded, under conditions that can leave no doubt as to the accuracy of the observation, which have at some seasons shown a marked activity in well-drained and otherwise well-cared-for districts, and have had but limited development in other portions of the same city, where drainage is defective and crowding marked.

"The difficulties of interpreting vital statistics, for the purposes of the sanitarian, are by no means small. We have not been gathering them for periods of time sufficiently long, over territories sufficiently wide, to justify definite conclusions upon a large number of public health questions. Before the beginning of the Christian era, the bubonic plague was the one great epidemic of the middle ages. The pestilence raged with such fury that 100 000 persons perished in London in 1665. The retreat had already begun when London was burning, and Western Europe, by no effort of her own, was at last free from the most fatal epidemic of modern history. In the years from 1800 to 1804, scarlatina was prevalent in Ireland, and very fatal, while in the succeeding years, down to 1831, the disease had so far changed its character that physicians in large practice could say that they had never seen a fatal case. Therefore medical men were led to believe that this change was the result of better treatment. In 1831, however, an outbreak of scarlet fever took place which had all the characteristics and all the malignancy of the earlier epidemic."

I would also refer further to Dr. Wolcott's and Dr. George M. Sternberg's address as Presidents of the American Board of Public Health, as to the value of plate culture of organisms and of the sterilization of water.*

"With regard to the development of typhoid fever and cholera, the literature is very extensive, and hygienists have not yet arrived at any settled theory; they neither agree upon their facts or upon the causes. We believe with Dr. Currier that water becomes purified by flowing as a fact, and as a necessity that there must be some means provided by nature to destroy the excess of pathogenous microbes. If it is done by saprogenic microbes, or the bacteria of putrefaction, it might be well to increase the production of these last, and let higher organisms absorb the survivors—keep the aquarium balanced. In fact the pathogenic organisms must be very much in the minority, and subject to many destructive influences. It is doubtful how far certain pathogenic forms are specific causes of the disease in which they have been found in the tissue. The pneumo-coccus is announced as the germ of consumption, and yet there are microbes in the normal saliva of man which by injection produce the same results as the pneumo-coccus.

"Numerous bacteria exist in the digestive canal of a man in good health. Recent researches tend to show that these microbes are not only

* Troussart on "Useful Microbes."

innocuous, but that they play an active part in gastric digestion, and especially in the transmutation of albumens into peptones. Since they are, in fact, living ferments, the transmutation is retarded if these microbes are eliminated. It is therefore probable that they manufacture pepsin." Pasteur's experiments also tend to show that microbes aid the germination of plants. "If the microbes contained in vegetable mould are withdrawn from it, without taking away any constituent, germination is retarded and effected with difficulty." If they are withdrawn from the animal frame, may not the same effect be produced on generation.

We take into our system some half a million microbes per day, which, according to some medical authors, are the food of the phagocytes or leucocytes, on which the healthfulness of the blood depends. Whether it is so or not, in view of the immense numbers and diffusion of microbes, it is evident it will be impossible to try the experiment of complete sterilization.

The literature of microscopy is pleasant reading, but it should be supplemented by a comparison with death and disease rates, and by practical observations of what we can see directly with our eyes.

The office of Vital Statistics is the most important one in our Boards of Health; the officer in charge should be intelligent and active, results should be tabulated and published, and all the conditions should be noted bearing at all on the probable cause of the disease.

Prof. Albert R. Leeds.—In attempting to discuss the extended paper of Dr. Currier, there is considerable difficulty, due to the many disputed points he has touched upon, and the necessity of often-repeated and most careful experiments requisite to arrive at anything like definite conclusions of practical value. In the first place, the views of Pettenkofer and the champions of the so-called "ground-water theory" of the causation of epidemics, are placed in comparison with the more recent "drinking-water theory," and the author presents no very definite conclusions as to the truth or falsity of either. I have supposed that it would reflect the views of the majority of those who have followed the long-continued controversy on this subject, to assign to the hypothesis of Pettenkofer and the Munich school a historical value mainly, while the great consensus of opinion is definitely in favor of the hypothesis which has been worked out by the more exact and more advanced experimental methods adopted by Pasteur, Koch and their host of followers.

The author states his belief that a water containing a large number of bacteria, especially if many varieties are detectable, is undesirable as a beverage so long as it has not undergone the sterilizing effect of heat. From the form in which this statement is put, it would seem that such a bacteria-rich water would be desirable as a beverage after it had undergone the sterilizing effect of heat, and I desire to learn whether this is the author's meaning.

Furthermore, in the case of any particular water, how many bacteria

and how many varieties should it contain before it would become undesirable before, and desirable as a beverage after, it had undergone heating. This is a practical question of immediate importance to the water-drinker. The Croton water, for example, frequently contains over four hundred colonies per cubic centimeter, and sometimes has over one thousand. The author found in the Delaware River, at Water Gap, three thousand four hundred colonies. This water, on the score of chemical purity, was recommended by the officers of the survey for the future supply of Philadelphia. And yet the number of bacteria is twice that reported by the author as present in the Passaic River, which, on the score of both common observation and chemical analysis, is one of the most polluted streams in this country.

Is it not true, as a matter of fact, that the one thousand colonies in the Croton water, the three thousand four hundred colonies in the Delaware water, weigh but little in the estimation of the bacteriologist if he feels sure on other grounds that the Croton water-shed, and the Upper Delaware water-shed, are demonstrably free from sources of serious sewage pollution?

I should be glad if the author would point out how the very few figures he has given, establish the fact of the self-purification of the streams examined. In the case of the Mississippi, the Passaic, the Delaware and the Schuylkill, there is an increase in the stated number of bacteria as we go down stream—how is this to be reconciled with the idea of self-purification. Also, if the author were to explain in what manner the old Croton Aqueduct affords opportunity for thorough aërification of the Croton water; which although dark throughout, and apparently different in many respects from ordinary flowing streams, is properly to be regarded as an ideal stream, and one admirably adapted for testing the question at issue.

In the same connection Dr. Currier calls attention to the fact of a slight epidemic of typhoid fever at Port Jervis, on the Upper Delaware, beginning October 1st, 1883; and apparently connects it with an outbreak of typhoid in Philadelphia, in January, 1884. Are we to understand his recommendation that the water should come to Philadelphia from a remote location through an aqueduct, to mean, that if so conveyed, the typhoid germs emanating from Port Jervis would have been destroyed; whereas with the apparently possible opportunities of self-purification afforded in so great a flowing river as the Delaware, they escaped destruction in the flow of more than a hundred miles.

It is important to bear in mind that the results of bacteriological examinations vary enormously, when they are made at different times and under different conditions. As an illustration I would quote the condition of the Passaic River during the summer and autumn of 1887. Those who are interested will find in the reports to the Newark and Jersey City Aqueduct Boards from 1881 and 1886 the chemical evidence,

on which I was led to infer that the large amount of sewage introduced at Paterson was oxidized at such a rate, that in case no further sewage were introduced lower down, the Passaic would have returned to the same condition as above the Great Falls during a flow of 16 miles. The reasoning is based upon the fact that while the dissolved inorganic substances go on steadily increasing in amount, the dissolved organic compounds exhibit a progressive diminution. A similar fact was noted in the condition of the Hudson River after receiving the sewage of Troy, and is stated in the reports to the Albany Special Water Commission. Also in the reports of the Philadelphia Water Department, as true of the improvement in the character of the Schuylkill River water, in its flow of 7 miles below the influx of the sewage from the town of Manayunk. In the case of the Hudson River, a corresponding series of biological analyses was made of the waters below Troy; and while the biological analyses did not correspond exactly with the chemical, the decrease in the number of bacteria as a general rule, corresponds with the oxidation of the dissolved sewage contamination.

Besides the evidence contained in the reports above alluded to, showing the dangerous pollution of the Passaic River, there is a further report, made at the desire of my colleagues of the State Board of Health in the year 1887, in which are given the results of a combined chemical and biological examination. In that report the condition of the Pequannock River above Butler is taken for comparison, and its great chemical purity is shown, with the corresponding low number of bacteria, of 70 colonies per cubic centimeter. The monthly analyses of the Hackensack River during the past 5 years having shown that with the exception of its somewhat high percentage of peaty matters, it was otherwise pure, this was examined and it was found to contain at the time of the investigation 200 colonies per cubic centimeter. But the Passaic, above the Great Falls, contained 4 000 colonies, while below, after receiving the Paterson sewage, they were innumerable. One mile below Paterson there were 72 000 colonies; and two miles below, 64 800. These enormous numbers are evidence certainly of great pollution, and at the same time of an apparent progressive improvement going down stream.

But other tests made lower down did not show such a progressive improvement, nor can I well see how this was to be anticipated, considering the variable increments of sewage coming in at the city of Passaic, the second river, the third river; and what is carried up stream even beyond the Newark and Jersey City intakes by the tidal flow, carrying with it the sewage emptying into the Passaic from the city of Newark. So that while thirty determinations of the number of bacteria at different points were made, they appeared insufficient to generalize from. I shall simply note here, as a point less studied perhaps by other observers, that the Passaic River below Paterson,

where the colonies of bacteria were so numerous as to defy counting, contained in solution but 2.97 cubic centimeters of oxygen per liter, while above the Great Falls it had 6.57 cubic centimeters. The Pequannock exhibited nearly the point of saturation with oxygen, or 7.22 cubic centimeters. So far as the evidence at present in our possession is concerned, it appears to show that with the incursion of sewage into a stream, whether from sewage or drainage, its content of dissolved organic nitrogen rises, and at the same time the number and variety of bacteria, while the percentage of dissolved oxygen sinks; and that when this sewage is submitted to the action of the various nitrifying and other bacterial ferments in a flowing stream, its organic nitrogen is oxidized, and the sewage is progressively destroyed. The evidence would appear to show that the multiplication of bacteria first takes place; then afterwards, along with the destruction of sewage, their progressive diminution. Such appeared a fair construction to put upon the results of the examination of the water of the Hudson River after receiving the sewage of Troy, of the Schuylkill water after receiving the sewage of Manayunk, and of the Passaic after receiving the sewage of Paterson. But a vastly greater number of analyses and determinations are needed, to speak with certainty upon these points. Similarly the number of bacteria in the Croton water varies between very wide limits. It may fall much below a hundred, and again it may rise, after a fall of rain or an increase of temperature, above a thousand. But except for the reason that the sanitary cordon around the streams on the Croton water-shed is not as yet rendered perfect, I don't think any one would seriously suspect that, even with 1 000 bacteria per cubic centimeter, the Croton water is necessarily dangerous to drink. And such is the character of these variations, that while the figures given by Dr. Currier show a diminution along the course of the Croton Aqueduct, an eminent bacteriologist, especially familiar with the Croton water, stated to me that at times these figures would be reversed.

Rudolph Hering, M. Am. Soc. C. E.—The subject of Dr. Currier's paper is certainly one which is of great importance to those engineers whose business it is to arrange for water supplies and disposal of sewage. I was in hopes, inasmuch as there is still a great deal of darkness on the subject, that Dr. Currier would give us a large amount of additional light which would help us in our work. But, while I think his paper is a very able exposition of much of the matter known at the present time, I was disappointed to see that little had been done lately which could be of much assistance to us.

Regarding his statement of the different theories held in Europe and America as to the relation which the height of ground water holds to the prevalence of certain diseases, I recall an interview I had some years ago with Dr. Pettenkoffer on this subject, when I was surprised to see the strong evidence which had been collected. The tables he showed me

were certainly remarkable, as demonstrating the relation of the mortality of typhoid to the ground-water level in Munich. Later I saw similar tables for Berlin and other cities of Germany, all of which showed that when the mortality was high the ground water was low, and vice versa. I thought at the time, and this idea seems to be held by a good many, that the explanation of this peculiarity might be as follows: the time when the ground water is low and the death rate is highest, corresponds with the time when the streams are low. The pollution derived from the soil, from manure and decaying vegetable matter, is then relatively greatest; and during long dry spells there is also a great deal of dust in the air, which settles upon the water more than at other times. But the "drinking-water theory" is also supported by strong evidence, as, for instance, by the epidemics at Plymouth, Pa., and many other places. Yet we have cases which are authentic, showing that typhoid fever could not have been transmitted by drinking-water. It therefore seems as though neither theory were quite satisfactory, but that the modern assumption, that the bacteria or their products are the real cause of the disease, may reconcile both of the older ideas.

Chemistry alone does not seem sufficient to determine the presence of these bacteria, as I am informed that there may be 500 000 in a cubic centimeter without being discovered through any chemical means. I was in hopes to hear something about the typhoid bacillus, which seems to be especially important. The Massachusetts State Board of Health is about to experiment with this bacillus, and to ascertain, if possible, its life and behavior in soils and water. This board is doing some excellent work, which will undoubtedly help the engineering profession very much. I do not think that anywhere in the world there is such a fund of facts relating to the purification of water as this board has collected.

In enumerating the various causes for the disappearance of organic pollution in water, Dr. Currier mentions deposition, by which bacteria tend to settle. He also mentions a number of instances which show that oxidation and the development of bacterial life is restricted by light. The English Rivers Pollution Commission, through the works of Dr. Frankland, who was in charge, seemed to show quite the contrary, namely, that light rather invited oxidation. They say that such oxidation is more active in sunshine than in shade, and is almost entirely arrested at night, or when the thermometer approaches the freezing point, showing that oxidation depends on the same conditions as those favorable to the life of low organisms. It may be, however, that more recent investigations have shown that these assertions need qualification.

Regarding large filters, Dr. Currier says that when they are carefully managed they effect great improvement in inferior waters. It is precisely on this subject that the Massachusetts State Board of Health has reached some definite and more or less new results. They have erected ten large filter-beds, consisting of tanks, each 16 feet in diameter, and

filled with different kinds of material, such as coarse sand, fine sand, loam, garden soil and peat. They have experimented not only with the water from the city supply, but also with sewage. The results obtained differ in some respects from what has formerly been supposed to be true. For instance, it has been found that peat, which is mentioned in different works as being a good material with which to purify sewage, is not at all capable of purifying it for any length of time. The board find that the purification of water depends on the physical condition of the material through which it filters, on the fineness of its grains, on its porosity, on the continuity of the pores which permit the air to follow the water or sewage when it is intermittently applied, and upon the presence of bacteria which effect the nitrification of the organic matter.

In experimenting with different kinds of soil, different degrees of porosity, etc., the board find that the best material for purifying sewage is sand of the fineness of common mortar sand. That the purification is not a straining process, they have proved by pouring sewage upon coarse gravel stones, 5 feet deep, from which all sand had been washed. When applied intermittently, a little at a time, at the rate of 80 000 gallons per acre daily, "each stone was kept covered with a thin film of liquid, very slowly moving from stone to stone and continually in contact with air in the spaces between the stones. The liquid, starting at the top as sewage, reached the bottom within twenty-four hours with the organic matter nearly all burned out."*

The board has further found that a certain time elapses before the nitrification sets in, and that by a persistent application of water or sewage the capacity of a given filter can be increased. It has been found that "a bed of coarse mortar sand, having particles about $\frac{5}{100}$ of an inch in diameter, there can be filtered intermittently for an indefinite period —*i. e.*, year after year—from 50 000 to 100 000 gallons of ordinary city sewage upon an acre, daily, without any accumulation of filth in the sand after the first year, and giving a bright, clear, colorless water, which chemical and biological analysis show to compare favorably with water from some of the wells used for drinking in some of the thickly settled parts of towns and cities in this State"* (Massachusetts). With finer sand, having grains which were but $\frac{5}{1000}$ of an inch in diameter, there could be filtered daily from 15 000 to 30 000 gallons per acre with a complete removal of all bacteria, and with a purity greater than that of most of the drinking-water supplies of the State.

The water used in Lawrence for domestic purposes when filtered through fine sand, could be applied at the rate of 3 000 000 gallons per acre, and thereby be rendered pure.

While the principles of purification through sand are not directly applicable to the purification of polluted water in streams, yet they may give us a clew by which we may also determine under what conditions

* "Lend a Hand," September, 1890.

we can best purify foul waters when mingled with the comparatively pure waters of running streams; for that reason I thought it might be of interest to mention the results which have been reached in Massachusetts.

The CHAIR.—Are these results contained in the last reports of the board?

Mr. HERING.—Some of them are, and others appeared in print in a short paper, published not long ago, written by Mr. Mills, who conducted the experiments.

Mr. WORTHEN.—The results, as I understand, will be published in full in the report of January.

Mr. HERING—I would like to ask Dr. Currier whether he took account of the question of dilution when he gave the number of bacteria in a cubic centimeter of water; many of these results seem to prove the reverse of what he wishes to prove regarding the self-purification of streams. In the case of the Kaaterskill brook, if I remember rightly, he gives 54 bacteria per cubic centimeter, and 1½ miles below that point he gives 49. Now, if in that 1½ miles this brook increased its flow 10 per cent., it would show that the same number of bacteria were contained in the cross-section, and that, therefore, there was no diminution in the number of bacteria. Again, in the case of the lake in the Rocky Mountains, he says there were 154 bacteria per cubic centimeter in the stream leading to it, and in the lake, which is quite large, he finds 43 bacteria in a cubic centimeter. It therefore seems that in going down stream, the total number of bacteria in the water is increased. But in many cases no doubt the reverse is to be found.

Dr. CURRIER.—Mr. Hering speaks of my wishing to prove a certain point; I merely show the result of a perfectly impartial investigation; the paper is simply a presentation of facts as I found them.

It must appear unsafe to consider that a river sufficiently purifies itself within a short distance from the entrance into it of a considerable amount of sewage or other contamination.

The slow filtration, which proved so satisfactory in certain of the Massachusetts experiments, produces very much purer water than is obtained when a large volume of bad water is rapidly passed through the usual large sand filter.

J. J. R. CROES, M. Am. Soc. C. E.—That the drinking of water may produce or aggravate disease in the human body, has been conceded by physicians for a great many years. The exact conditions of water under which injurious effects may be produced, have been the subject of investigation by a number of different classes of observers. Up to a very recent period the chemical composition of the water was the only subject of investigation, and disease was supposed to be dependent on the chemical action of certain constituents in the water on the tissues of

the body. About fifteen years ago it became evident, as the result of progress in microscopical and chemical investigation, that the forms of animal and vegetable life which are to be found in waters generally only by microscopical examination, produced, by both their growth and decay, certain effects upon the human system, without, at the same time causing any very material change in the chemical constituents of the water.

The vegetable organisms are classified as algæ, and have been discussed at some length in papers heretofore presented to the Society. There are also found in water, however, great numbers of what is now considered to be the lowest form of animal life, the organisms classified under the general head of bacteria, which are visible only under a microscope of high power, being generally less than the one-five thousandth part of an inch in length. These small creatures possess, however, a decided individuality, and are found to be divided into numerous families, each differing from the other in shape, size and color.

The careful investigation of Dr. Koch and other scientists appears to have established the fact, that certain species of these infinitesimal creatures are found in considerable quantities in the human body, only where certain diseases are known to exist, and the presumption is, therefore, that such diseases are produced by these species. These bacteria are found in water, and it may safely be assumed that where a water contains a large number of such species as are known to exist in certain tissues of the human body, only when these tissues are known to be diseased, such water cannot safely be taken into the human system. The reason for the appearance, growth and disappearance of these organisms in waters has not been accurately determined; but that injurious species do appear in running streams, and that the number of them increases or diminishes as the case may be, is well established. The object of the investigations, the results of which are embodied in Dr. Currier's paper, has been to discover more particularly whether in a running stream, in which at some point on its course an excessive number of these injurious bacteria have been discovered, there will be an increase or a diminution of such organisms in the course of the natural flowing of the stream through a channel, in which no apparent exciting cause for their generation or growth has occurred.

The method of investigation of these organisms is as follows: A preparation of ten parts of strong beef tea and one part of gelatine is submitted to steam heat long enough to kill any bacteria which may be in it, for it has been found that these small creatures cannot stand boiling. This mixture solidifies in cooling. While the gelatine is soft (at a temperature a little above 73 degrees Fahr.), 1 cubic centimeter or about a quarter of a teaspoonful, of the water to be examined, is added to the gelatine drop by drop, and the bacteria in the water are diffused throughout the gelatine by rotation of the containing tube. The mass is poured into a shallow glass dish and carefully protected from the con-

tamination of the air, and allowed to solidify. On examination with a microscope a few days later, the individual bacteria in the water which has been added are found to have increased and multiplied to an enormous extent, each individual being now the center of a mass of many thousands, and even millions, of individuals. These masses, called colonies, are visible to the naked eye, and their appearance differs greatly. The number of the colonies is counted, and this number affords some criterion of the quality of the water.

To know whether the individuals composing these colonies are injurious or not, reference must be had to the investigations made by the scientific observers of bacteria. Many of them are supposed to be perfectly harmless, while others are pretty well proven to be disease-producing. The character is discovered by finding out what food they thrive on best, and what forms they assume in generation and growth. For this purpose various "culture media" are prepared, which are concentrated extracts of various nutritious substances, stiffened with gelatine or similar substances, and put in test tubes. A fine platinum wire, having been first passed through flame to kill any germs which may be on it, is touched to a "colony" and then plunged into a tube containing a "culture medium." The bacteria thus transplanted generate in a few days; and their growth and form can be studied under the microscope, and their class determined from their form and their rate of growth in that "culture medium."

Now, by taking samples of water in a stream at any point, and taking other samples of, as nearly as may be procured, the same water at another point lower down on the stream and treating both samples alike, it is possible to determine both whether the bacteria have increased or diminished in number, and whether such change of number has been greatest in the injurious or the harmless species. In general, if the number has greatly diminished, it may be assumed that the quality of the water has improved, for the harmless varieties are the more hardy, and appear moreover to destroy the injurious ones when they are brought into conjunction with them, without the addition of fresh supplies of bacteria from foreign sources.

George W. Rafter, M. Am. Soc. C. E.—Dr. Currier's paper discusses one phase of the question of self-purification of water in flowing streams. There are, however, other phases of considerable importance, and the following, without exhausting the subject, may be taken as a partial view of some of the causes operating to produce such self-purification.

Among the invertebrata there are certain classes of microscopic animals which, under favorable conditions of sufficiency of food supply, multiply in enormous numbers. As common representatives of these minute animals, we may mention: (1) certain of the filth infusorians, as for instance *Paramecium;* (2) *Hydra*, as the typical representative of

the order Hydroida; (3) certain of the Rotifera, of which *Lacinularia* and *Conochilus* may be cited as perhaps typical forms; (4) the numerous species of animals included in the entomostracan crustacea; (5) *Gammarus*, or the fresh-water shrimp; and (6) the larvæ of a number of water insects.

In comparison with bacteria the infusoria are creatures of vast size, even though some species are as small as $\frac{1}{1000}$ inch in length. *Paramecium aurelia*, a form found I believe almost invariably wherever putrefaction of animal matter is taking place in water, is an infusorial giant, mature individuals measuring as much as $\frac{1}{90}$ inch in length. *Paramecium bursaria*, however, is much smaller, about $\frac{1}{250}$ inch being the usual length.

In addition to *Paramecium*, there are a number of other ciliate infusorians, which are almost invariably found in water containing organic matter undergoing decay, and examinations made by the recently developed methods of biological enumeration, indicate that from twenty to fifty such forms may be found in every cubic c.c. of badly contaminated water; but whether any such numbers would be found in running streams, even though flowing slowly, I have had as yet no means of determining.

Any notice of the infusoria in relation to the self-purification of contaminated waters, would be incomplete without some reference to *Euglena* and the allied genera. In standing waters *Euglena viridis*, an infusoria of bright green color, is frequently present in such quantity as to impart a green color to the water. Its length varies from $\frac{1}{140}$ inch to $\frac{1}{90}$ inch. The vast quantities of *Euglena* which are met with under favorable conditions are sufficiently accounted for when we learn that it may multiply, not only by fission, or by the division of one individual into two, but it further multiplies by the "subdivision of the entire body substance into sporular elements, and by the development of independent germinal bodies out of the substance of the endoplast."*

Euglena is generally found in quantity in streams contaminated with sewage. *Hydra* is an animal of considerable size, frequently reaching a length, when fully extended, of nearly an inch. It is attached to water plants in quantity in stagnant waters, and voraciously devours everything coming within its reach.

Rotifers frequently develop in vast quantity in waters carrying large amounts of organic matter; and among such *Lacinularia socialis* may be taken as typical. This creature is usually attached to water plants along the margins of slowly running streams; and in favorite locations at certain seasons, many hundred thousand colonies will be found in a limited space. The colonies are about $\frac{1}{5}$ inch in diameter, and frequently contain from fifty to one hundred individuals, each about $\frac{1}{12}$ inch in length. A single sprig of water plant has been found to support nearly one hundred colonies.

* Kent, "Manual of the Infusoria," page 379.

Another rotifer which may be mentioned is *Conochilus volvox*—a free-swimming, social form—with the colonies containing from seventy to one hundred individuals. The colonies are on an average $\frac{1}{20}$ inch in diameter, with the single members $\frac{1}{40}$ inch in length.

Probably the Entomostraca are of the animal forms the most efficient assistants in the self-purification of running streams. The vast numbers in which they develop, and the readiness with which they devour all sorts of filth, render them worthy of more extended study, from an economic point of view, than they have yet received.

As illustrating the forms especially worthy of attention, in this connection, may be mentioned *Daphnia*, *Ceriodaphnia*, *Cypris*, *Cyclops* and others. These are all found in waters containing decaying organic matters, and if the water is intended for domestic use, their presence in quantity may be taken as danger signals.* On the other hand, their presence in quantity may be taken to indicate a step in the process of self-purification of contaminated waters. As many as one thousand four hundred *Ceriodaphnias* have been counted in a single quart of such water,† and this number by no means exhausted the visible life in the sample.

A study of the Entomostraca, and observations of their immense fecundity and tendency to act as scavengers, led at an early day to singularly correct views as to the causation and spread of disease. Thus Otho Fredericus Müller, in his work on the Entomostraca, published in 1785, says: "The time is at hand when the causes of disease shall not only be sought after in the air, in our method of living, etc., but in the incautious use of waters often abounding in innumerable animalcules." The fertility of these little animals has already been referred to, and by way of illustrating it, reference may be made to Jurine's computation, that a single female *Cyclops quadricornis* might in one year have a progeny amounting to four billion, four hundred million.‡ The following are the average lengths of some of the animals of this group: *Daphnia*, $\frac{1}{10}$ inch; *Simocephalus*, $\frac{1}{8}$ inch; *Cyclops*, $\frac{1}{10}$ inch; and *Cypris*, $\frac{1}{12}$ inch. *Gammarus*, another crustacean of the order Amphipoda, is a denizen of sluggish-flowing, contaminated streams, where it may be frequently found in great quantity. This animal, when full grown, attains a length of $\frac{1}{2}$ inch. The larvæ of a number of insects pass their larval stage immersed in water, and among such the larva of the mosquito may easily take a high rank for large numbers.

The foregoing exhibits, in a very incomplete way, a few of the animals which assist in the self-purification of a running stream. The number of species which actually assist in such work is very great, and a mere enumeration of them would require considerable space. As to the

* Herrick, "Crustacea of Minnesota."

† Herrick, *loc. cit.*

‡ Baird's "British Entomostraca," page 190.

definite part played by each species little can be said, as, with the exception of the Entomostraca, none of them have been studied in reference to their economic value in this direction. The exception noted in the case of the Entomostraca is a partial study made by Dr. H. C. Sorby, of England, a few years ago.

Enough can be gathered, even though we possess little definite knowledge, to justify saying that animals of the classes under consideration play a very important part in the so-called self-purification of streams. Minute plants may also be considered as assisting greatly in such work, but this part of the subject I leave untouched at this time.

The question of self-purification may, however, be somewhat simplified, if we consider just the distinction which marks the division line between animals and plants. The specific difference may be readily appreciated, by considering that animals always require organized food; they seek those substances in which hydrogen, nitrogen, carbon, sulphur, etc., have been already assimilated into living forms, such living forms themselves being either animal or plant. Plants, on the other hand, have no power of assimilating organized food; they require rather the elements hydrogen, nitrogen, carbon, etc., in their primal state. In a general way, it may be said that this distinction holds good through the whole scale from the highest to the lowest. Indeed, when we come to deciding a difficult case, as for instance whether a given form belongs to the Protophyta or the Protozoa, we take advantage of this distinction, and the natural line of study is to determine in which way food is taken by the unknown form.

A proper appreciation of this distinction will assist greatly in understanding the phenomena exhibited by streams in the process of self-purification. Thus we seem justified in concluding, that if contaminating organic matter in streams is to be reduced to an innocuous form, without the intervention of foul, odor-producing, putrefactive processes, it will be accomplished, in the earliest stages at any rate, by the assistance of animals rather than plants. Just how animals and plants assist in the process of self-purification, is finely exhibited by the paper of Dr. H. C. Sorby herewith appended, entitled, Detection of Sewage Contamination by the Use of the Microscope, and on the Purifying Action of Minute Animals and Plants. Dr. Sorby says:

By studying with the microscope the solid matters deposited from the waters of a river, the previous contamination with sewage can usually be detected without any considerable difficulty. If the amount be serious, the characteristic particles of human excrement can easily be seen; and if it is small and has been carried a long way by the current, it can usually be recognized by means of the hairs of oats derived mainly from the droppings of horses, which resist decomposition for a long time, and are not consumed as food by minute animals. I, however, do not propose to enter into detail in connection with this part of my subject, but specially desire to call attention to the connection between the number of minute animals and plants and the character of

the water in which they live, and also to their influence in removing organic impurities.

For some time past I have been carefully ascertaining the number per gallon of different samples of river and sea water, of the various small animals which are large enough not to pass through a sieve, the meshes of which are about $\frac{1}{200}$ part of an inch in diameter. The amount of water used varies from ten gallons downwards, according to the number present. By the arrangements used there is no important difficulty in carrying out the whole method in a satisfactory manner. I confine my remarks entirely to general mean results. The chief animals met with in fresh water are various Entomostraca, Rotifera and the worm-like larvæ of insects. I find that the number per gallon and percentage relationships of these mark, in a most clear manner, changed conditions in the water, the discharge of a certain amount of sewage being indicated by an increase in the total number per gallon, or by an alteration in the relative numbers of the different kinds, or by both. All my remarks apply to the warm part of the year, and not to winter.

It is known that Entomostraca will eat dead animal matter, though probably not entirely dependent on it. I have myself proved that they may be kept alive for many months by feeding them on human excrement, though they soon died without it. If the amount of food in any water is small, not many of such animals can obtain sufficient; but if it be abundant, they may multiply rapidly, since it is asserted that in one season a single female Cyclops may give rise to no less than four thousand millions of young. In stagnant muddy ponds, where food abounds, I have found an average of 200 per gallon. In the case of fairly pure rivers the total number of free-swimming animals is not more than 1 per gallon. I found, however, that where what may be called sewage was discharged into such water, the number per gallon rose to 27, and the percentage relationships between the different groups of Entomostraca were greatly changed. In the Thames at Crossness, at low water, the number was about 6 per gallon, which fell to 3 or 4 at Erith, and was reduced to less than 1 at Greenhithe.

There is, however, a very decided limit to the increase of Entomostraca when the water of a river is rendered very impure by the discharge of too much sewage, probably because oxygen is deficient, and free sulphide of hydrogen present. Such water is often characterized by the great number of worm-like larvæ of insects. Thus, in the Don below Sheffield in summer, I found the number of Entomostraca per gallon only about one-third of what it is in pure waters; whilst on the contrary, the number of worm-like larvæ were more than 1 per gallon.

Now, if the minute free-swimming animals thus increase when a certain amount of sewage supplies them with ample food, it is quite obvious that they must have a most important influence in removing objectionable impurities. The number of excrements of Entomostraca in the recent mud of such rivers as the Thames is most surprising. In one specimen from Hammersmith, I found that there were more than 20 000 per grain; and the average number at Erith in August, 1882, was about 7 000, which is equivalent to about 200 000 per gallon of water at half ebb, from the surface to the bottom. This enormous number must represent a very large amount of sewage material consumed as food; and though, as in the case of larger animals, a considerable part of their excrements no doubt consists of organic matter capable of putrefaction, yet there can be no less doubt that the amount entirely consumed in the life-processes of these animals is also great.

As named above, I kept Cyclops alive for many months by feeding

them on human excrement. It is thus easy to understand why, when they abound in the Thames, the relative amount of human excrement is very considerably less than in the winter, when their number must be much smaller. We thus appear to be led to the conclusion that when the amount of sewage discharged into a river is not too great, it furnishes food for a vast number of animals, which perform a most important part in removing it. On the contrary, if the discharge be too great, it may be injurious to them, and this process of purification may cease. Possibly this explains why in certain cases a river which is usually unobjectionable may occasionally become offensive. It also seems to make it clear that the discharge of rather too much sewage may produce relatively very great and objectionable results.

Though such comparatively large animals as Entomostraca may remove much putrefiable matter from a river, we cannot suppose that, except incidentally, they remove such very minute objects as disease-germs; but it would be a subject well worthy of investigation to ascertain whether the more minute infusoria can, and do, consume such germs as a portion of their food. If so, we should be able to understand how living bodies, which could resist any purely chemical action likely to be met with in a river, could be destroyed by the digestive process of minute animals. Hitherto, I have had no opportunity for examining this question critically, but have been able to learn certain facts, which at all events show that it is well worthy of further examination. It is only during the last month that I have paid special attention to the number of larger infuscria and various other animals of similar type met with in the waters of rivers and the sea, which can be seen and be counted by means of a low magnifying power. At low water in the Medway above Chatham, in the first half of June, the average number per gallon has been about 7 000, but sometimes as many as 16 000. Their average size was about $\frac{1}{1000}$ inch. Possibly the number of still more minute forms may be equally great; but if we confine our attention to those observed, we cannot but conclude that their effect in removing organic matter must be very considerable. Judging from what occurs in the case of larger animals, those $\frac{1}{1000}$ of an inch in diameter may well be supposed to consume as food particles of the size of germs. Up to the present time, I have however collected so few facts bearing on this question, that it must be regarded as a suggestion for future inquiry.

So far I have referred exclusively to the effect of animal life. Minute plants play an important part in another way. The number per gallon of suspended diatoms, desmids and confervoid algæ is in some cases most astonishing, and they must often produce more effect than the larger plants. As far as I have been able to ascertain, their number is to some extent related to the amount of material in the water suitable for their assimilation and growth. In the mud deposited from pure rivers their number is relatively small, but in the district of the Thames, where the sewage is discharged, I found that in summer their number per grain of mud at half-ebb tide was about 400 000, which is equivalent to about 5 000 000 per gallon of water. This is two or three times as many as were found higher up or lower down the river, and out of all proportion more than in the case of fairly pure rivers like the Medway. Their effect in oxygenating the water must be very important, since when exposed to the light, they decompose carbonic acid and give off oxygen, under circumstances most favorable for supplying the needs of animal life, and counteract the putrefactive decomposition so soon set up by minute fungi when oxygen is absent.

Taking all the above facts into consideration, it appears to me that

the removal of impurities from rivers is more of a biological than a chemical question; and that in all discussions of the subject, it is most important to consider the action of minute animals and plants, which may be looked upon as being indirectly most powerful chemical agents.

[Excerpted from the Journal of the Royal Microscopical Society, 1884, pp. 988–991.]

A number of photographs of the animal forms referred to in this discussion were submitted, from which Plates Nos. VI to IX have been prepared.

DESCRIPTION OF PLATES.

Plate VI.

An instantaneous photograph ($\frac{20}{1}$) of a living colony of *Lacinularia socialis.*

Plate VII.

A mature female *Daphnia pulex* ($\frac{30}{1}$) with eggs.

Plate VIII.

Fig. 1, $\frac{8}{1}$. Mature *Gammarus.*

Fig. 2, $\frac{20}{1}$. Female *Cyclops* with egg sacs.

Fig. 3, $\frac{34}{1}$. *Cypris.*

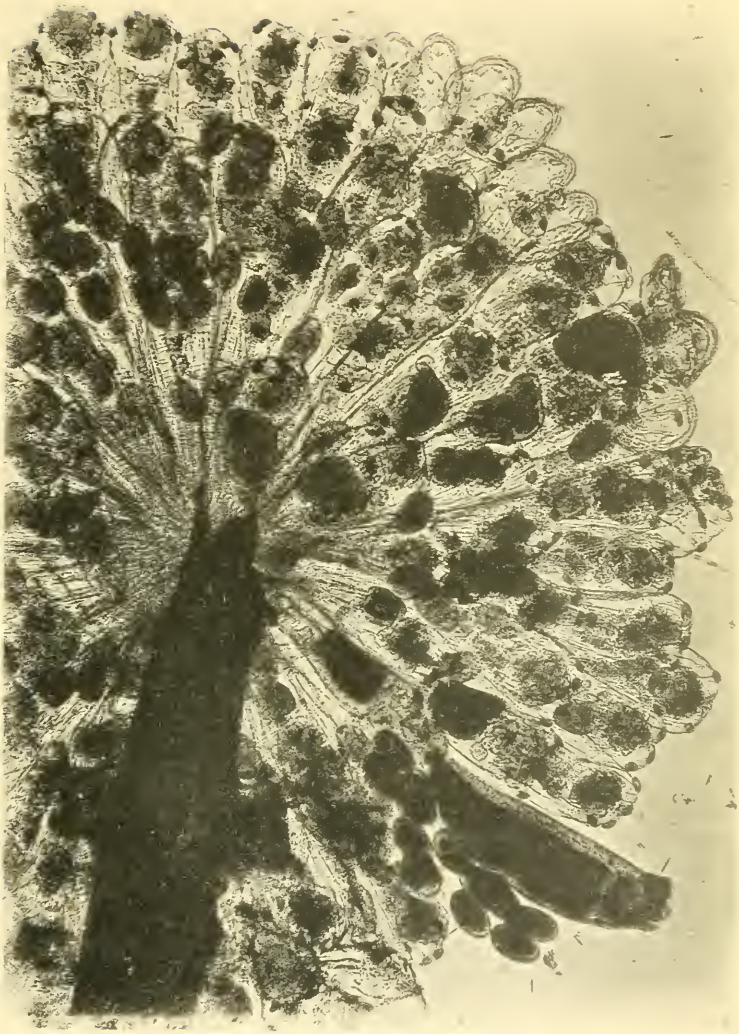
Plate IX.

Fig. 1, $\frac{30}{1}$. *Sida crystallina.*

Fig. 2, $\frac{30}{1}$. *Chydorus.*

Fig. 3, $\frac{21}{1}$. Female *Simocephalus* carrying eggs.

Transactions of the
AMERICAN SOCIETY OF CIVIL
ENGINEERS.
Vol. XXIV, No. 2.
Rafter on the
Self Purification of
Streams.



$\frac{20}{1}$

Photo-Micrograph by
Dr. J. EDW. LINE

$\frac{30}{1}$

Photo-Micrograph by
GEO. W RAFTER.

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Streams

Fig. 1. $\frac{8}{1}$

Fig. 2. $\frac{20}{1}$

Fig. 3. $\frac{34}{1}$

Photo-Micrograph by
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Fig. 1. $\frac{30}{1}$

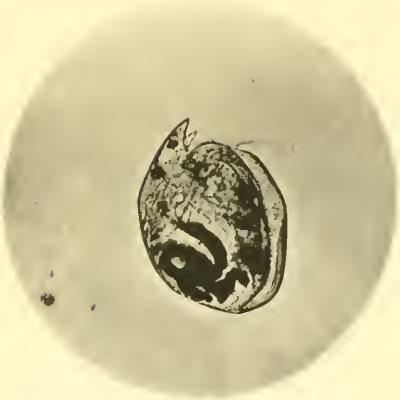

Fig. 2. $\frac{30}{1}$

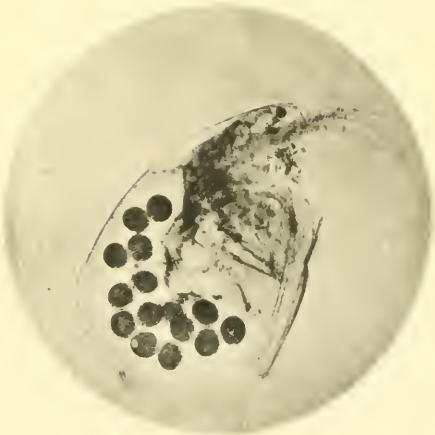

Fig. 3. $\frac{21}{1}$

Photo-Micrograph by
GEO. W. RAFTER.

S. WHINERY, M. Am. Soc. C. E.—It seems well enough established that polluted river-water tends to become purified when subjected to the influences brought about by the flow of the water, such as agitation, aërification and time; but the exact conditions under which this purification takes place seem not at all well understood.

We have a mass of testimony, collected by different observers, upon different rivers, which seems to show that in some cases very impure water becomes safe for domestic use after a flow of less than twenty miles, while in other cases the impurities are still present in dangerous amount after a flow of ten times that distance. It is possible, but not probable, that there is actually so great a difference in results as recorded observations seem to show. It is much more likely that the value of such observations is impaired, by the failure on the part of observers to secure the necessary uniform conditions under which the observations should be made. The sewage which pollutes a stream is often all discharged into it at one point, and very generally on one side only of the stream. In most cases it does not become at once fully commingled with the whole volume of water, and may not become so for a long distance below the source of pollution.

We know that the waters of two confluent rivers may flow side by side for many miles, before each loses its identity. Besides, rapids and eddies or whirlpools, may operate to concentrate the impurities at certain points more that at others. It is therefore to be expected that unless observations are made with the greatest care, and in sufficient numbers, and at a sufficient number of points to give correct averages, great variations and contradictory results will be obtained.

In view of these facts, it would seem that the simple plan of conducting experiments on small artificial bodies of water, where the conditions could be controlled and made uniform, would have suggested itself to specialists in this line of investigation; but if this has ever been done, I am unable to find records of the results.

It would seem practicable to make a series of experiments and observations on a small body of contaminated river-water, confined in a vessel or tank, where all the conditions of a flowing river might be so closely imitated as to make the results applicable to the river itself. It would be easy enough to provide means of artificial agitation, corresponding very closely to the current of the river, and to vary the rate of flow or agitation at will; to imitate very closely the form of cross-section and composition of the banks of the natural stream; to study the effects of sunlight and shade, and the influence of heat and cold; to determine whether sediment, in sinking to the bottom, carries with it any considerable amount of impurities or disease-germs, and to study any other phenomena connected with the problem. It ought to be possible in this way to determine with some degree of certainty, in what length of time, under the various conditions, contaminated water becomes pure enough for

domestic use. Also to study the effect of artificial methods of purification under definite conditions. The water in such a vessel or tank could be easily kept so completely commingled, that a few samples under the microscope would give reliable averages.

It might not be practicable to conduct all the experiments at one place, since the transportation of a sample of water from any great distance, might change its normal condition as taken from the river, but the apparatus could be readily moved from place to place as required. To one who is not a specialist in this line of work, it would seem practicable to attain results with a small expenditure of time and money, of far more value than desultory and uncertain tests of the waters of all the rivers in the country.

Dr. Currier.—Considering brevity as of the first importance, the author has, in the article discussed, given in the fewest words the result of voluminous reports of experiments. In the body of the communication will be found anticipatory answers, however brief, to nearly all of the very many questions put on the evening of November 5th, and to most of the inquiries and statements of those who spoke at the meeting of November 19th, in so far as these related to the subject-matter of the paper.

The allusions to the weighty facts and figures which the supporters of Pettenkoffer's theory produce, were made to show that the "drinking-water theory"—which the author is disposed to favor—is not the only one accepted by sanitarians. These great problems are at best very complex, and not so easily settled as extremists assume. The writer would distinctly state that he believes the harmfulness of polluted water to depend upon the fact that it contains harmful bacteria. No bacteriologist, believing in Koch's doctrines, would hesitate to give preference (so far as the particular sample is concerned) to a drinking-water having a considerable number of harmless bacteria, rather than to one having fewer bacteria, which were, however, of a distinctly infectious kind. We may doubt whether the healthy alimentary tract, is vulnerable to the bacteria of disease which are too often contained in drinking-water. It is presumably essential (at least in the majority of cases) that some departure from the state of perfect health of the mucous membrane must exist, in order that, for example, the typhoid bacillus shall, when swallowed, enter the system and produce disease. Yet it is the part of prudence for all to avoid the use of infected water. The introduction of the bacteria of putrefaction and decomposition with our food and drink, is in no wise desirable. The presence of these micro-organisms in the intestine tends to cause the evolution of undesirable gases, by their action upon the substances present; while the amount of salutary digestive potency which they possess, is very unimportant. They are vastly inferior in this respect to the normal digestive secretions.

As for the unusually large number of bacteria found present in the Delaware River, it may be repeated that the copious rains had washed much matter into the streams, and with it many bacteria. A more careful reading of the article would perhaps cause the querist to find the statement, that "one should not infer that the increase of 'typhoid' in Philadelphia was caused by the bacteria which had survived the 100-mile passage down the river." The stream flowing through the old Croton Aqueduct seemed a desirable one to test, since in its course it received no inflow except from the Bronx. The darkness of the conduit would not tend to lessen the number of bacteria present in the flowing water; and over the water a current of agreeable air was passing.

The results of biological examinations of water are considered most satisfactory, when the plates are prepared immediately after the sample is taken. Transportation to a distant laboratory, especially if the water is kept warm, may result in great increase. The high numbers which Professor Leeds found in the waters of the Passaic may have been due to the fact that he failed to plate the water as soon as his samples were taken from the stream. He must admit that Philadelphia would have a purer water supply, if the Delaware River received no contamination whatsoever between the "Water Gap," and the place whence it now draws a large portion of its supply from that river.

That harmful bacteria survive (at least occasionally) a passage of several miles down a stream, seems probable from the facts presented by the recent epidemic of typhoid fever at Albany. There the cases appeared to be almost entirely limited, to the districts where water from the Hudson River was drunk. (See New York papers of January 24th, 1891.)

It certainly is of vital importance, to keep the water-sheds from which we draw our supplies as free from all contaminations as we possibly can. "Only by vigilant and intelligent efforts can lasting and constant purity of the supply be maintained." The Croton supply is a comparatively "excellent water." This is shown by repeated bacteriological and chemical examinations, and furthermore by the very small number of cases of typhoid fever occurring, among those who regularly drink the New York hydrant water.

The author realizes how desirable it is that numerous observers make many examinations of various waters, and that these be frequently repeated through a long period of months or years. Such investigation involves a vast amount of systematized work and a liberal outlay. It is to be hoped that other wealthy States follow the example of Massachusetts in this respect. The results thereby obtained would be of great value.

[Dr. Currier's paper is summarized on page 40.]

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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Vol. XXIV.—February, 1891.

STREET RAILWAY TRACK.

By T. G. GRIBBLE, A. M. I. C. E.

WITH DISCUSSION.

The valuable paper by Mr. E. E. Russell Tratman upon the improvement of railway and street railway track, *Transactions* Am. Soc. C. E., March, 1890 pointed out as regards the latter, the direction which improvements should take, and gave critical descriptions of the various types of construction in use in this country.

The amount of space given by Mr. Tratman to larger railways in his paper left little room for the subject of street railways, and it will be attempted in this paper to pursue that subject somewhat further, and to show the objective points of English practice as compared with those on this side of the Atlantic.

America alone of the civilized nations has given free and full scope to the street railway, perhaps sometimes too much so, but if her municipalities have erred on the side of leniency to corporations at their inception for the sake of progress, they have known also how to make up for it afterwards in rates and taxes.

The tramway is the parent of the railway, but the offspring has so far outgrown the progenitor as to become to some extent its standard for

imitation. Rails like the "Doane" at Boston, for instance, are as heavy as anything on a trunk line, and heavier rails still are being laid on English tramways.

From the Coalbrookdale tram-slabs in 1767 to the first introduction of practical tramway building in England in 1857, by Mr. George Francis Train, the street railway was unknown, except in America. Snubbed by officialism, opposed by vested interests, hampered by prejudice and timidity, tramway development in England has been slow, but in one direction, that of road-bed and track, there has been progress, slow, also, but sure. The heavy vehicular traffic, and latterly the use of steam dummies upon the suburban lines, has compelled the use of a very substantial foundation and support to the rails, and whilst America has been teaching the old country in matters of rolling stock and traction, she is not unwilling under the altered circumstances of modern urban transit to turn over some back pages of English experience in the pathway of the cars.

The roadbed of railways and tramways can be more easily contrasted than compared. The conditions are radically different. On railways the track is always open to inspection and a decayed cross-tie can be replaced or a loose joint tightened up at any time, but on street railways there is nothing for trackmen to do, because there is nothing for them to see until the substructure fails and the pavement has to be removed.

The high speeds and heavy concentrated loads upon railways produce a series of shocks which require an elasticity in the rails not needed upon tramways, even on electric or cable roads.

The wear upon rails in streets is largely due to the vehicular traffic, the action of which is complicated, compared with that of the car wheel.

The interests to be considered in tramway construction are more diverse:

First.—There are the requirements of the municipal authority.

Second.—The interests of the company, as a commercial undertaking.

Third.—The comfort and convenience of the public who use the cars.

Fourth.—The comfort and convenience of the walking and driving community.

The points which street railway builders have aimed at more or less successfully from the first, have been the following:

1. An imperishable foundation, which need not be interfered with for the purposes of renewals.
2. An unyielding rolling surface.
3. A vertical face against which to lay the paving.
4. A minimum of renewals.
5. A minimum resistance to traction.
6. A smooth surface for passing vehicles.
7. A surface which vehicles will not use for running on.
8. A maximum of speed consistent with safety.
9. A minimum of first cost.

In too many cases the last of these objective points has been the greatest if not the only desideratum to the promoter. The comparative stress laid upon one or other of these points has greatly varied according to circumstances of country, of population and of available funds, but at the present time the tendency is toward uniformity. It is felt increasingly that a very few types of construction should be sufficient to meet all the requirements of the different cases which arise in practice. Those, for instance, which demand a continuous support, and those in which an intermittent support would be preferable. Those which call for a heavy or a light rail, and so forth, and it will now be attempted to analyze the foregoing list of subjects historically and critically with a special bearing upon the present-day problems.

The Foundation.

The streets and roads of cities, especially in old countries, have become sufficiently consolidated to receive a longitudinal bed of concrete without subsidence, and in such cases there can be no better material for the foundation, both from the convenient mode of depositing it *in situ* and from its great strength and durability within a few days after being laid. On soft or newly made road bottoms, it would be as imprudent to lay concrete as it would be to place it on railway embankments under locomotives. Electric railways are now frequently carried far out into the suburbs to develop real estate, and extensive road-making is undertaken to receive the track. Made-up ground, if properly drained and exposed to the weather for three years will generally be firm enough to receive concrete, but if the traffic over it has been light, it should first be well rolled with a steam roller.

Where there is any uncertainty as to the supporting power of the ground and concrete is demanded, it should be laid the whole width of the rails and for a short distance outside of them. It should be, moreover, of a sufficient transverse strength to act under partial settlements as a beam; that is to say, to be of a thickness of from 1 to 2 feet, which in this country would cost from $10 000 upwards per mile for foundations alone. Such an outlay as this would be prohibitive and not more effectual than a system of metallic ties at a quarter the cost.

The Eckington and Soldiers' Home Railroad Company of Washington, D. C., are laying a foundation of concrete between wooden cross-ties in the expectation that when the timber decays there will be sufficient supporting surface from the concrete alone, under and around the rail.

The concrete is deposited in a longitudinal trench under the rail, and the cross-ties are placed 15 feet apart, spiked to the rail in the usual manner. The concrete is afterwards packed around the rail for a depth of 3 inches, and the surface is finished off in asphalt. By this means a lighter section of rail can be used to obtain the same wear as in the English system, with 80 to 100-pound rails. The cross-ties furnish a temporary assistance until the concrete has attained its permanent tenacity. By the time they decay there will be no longer any need for them.

The new electric railway at Pittsburgh, which is to be equipped by the Thomson-Houston Company, is laid with a substantial foundation of concrete, making the total cost of single line $30 000, according to the *Street Railway Journal.* A 60-pound Wharton girder-rail is laid on sawn-oak ties, placed 2½ feet apart and bedded on a concrete foundation. The spaces between the ties are filled with broken stone, and topped out with concrete.

Neither of these methods, although great improvements upon the timber-stringer, can be considered satisfactory construction. Even wooden houses of the better class have brick foundations, but this composite street railway building resembles a substantial house of brick built upon a timber foundation.

The first concrete foundation laid in England was in 1870 on the North Metropolitan line, London; where a longitudinal trench 16 inches wide by 9 inches deep was laid under each rail, besides which a 3-inch bed of concrete was laid the whole width of the track. The rails were attached to wooden stringers resting on cast-iron chairs. This system of

foundations was followed by several other cities, and also the method of imbedding cross-ties of timber in concrete; there was, however, a longitudinal stringer resting on the cross-ties to which a flat rail was fastened.

THE DEAS SYSTEM AT GLASGOW, SCOTLAND.

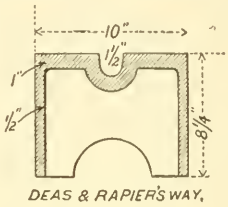


FIG. 1.

Almost at the same time as the London tramway, the Glasgow cast-iron way was laid, Fig. 1, in which, in addition to a longitudinal bed of concrete 18 inches wide by 6 inches deep, the cast-iron box was itself filled with concrete. This foundation has proved very satisfactory on a ten years' trial; although in some few cases, under the heaviest traffic of the wharves, a slight settlement took place, necessitating the lifting of the box.

A longitudinal bed of concrete has not only the advantage of less disturbance of the street when first laid, but it can be conveniently applied for replacing a wooden system by a metal and concrete one without interrupting the traffic. The wooden stringer can be underpinned with concrete during the daytime, and the iron stringer substituted during the short interval of night when the cars have ceased running.

As the use of Portland cement concrete for street railways, except for cable roads, is only in its first stages in America, it is greatly to be hoped that proper justice will be done to this most valuable material. The work of testing the cement, mixing the ingredients, and depositing the concrete, should be under an inspector who cannot be bought by the contractor. It is easier to "scamp" concrete than any other part of the work. On a work of sufficient magnitude there should be a cement-storing shed, with a testing office attached. There should be also a mixing machine, and facilities for rapid delivery of the material. Some contractors will, if not carefully watched, not only give short allowance of cement but work up leavings, half-set or quite set, into a fresh mixing.

A proportion of one of Portland cement to five of sand and gravel

or broken stone, is suitable to this work. It has a tensile strength of about 50 pounds per square inch after a week, increasing up to about 150 pounds, when a year old and upwards.

The crushing strength of the concrete itself is so greatly in excess of the loads that can come upon it, that failure never takes place in that manner when it is properly laid.

It is always a subsidence of the soil beneath the concrete which causes trouble, making it into a beam under transverse stress. An area of good soil forming a longitudinal support to the concrete under each rail 15 inches in width is approximately equal to the bearing surface under cross-ties 9 feet long by 9 inches wide, spaced 2 feet 9 inches apart. As this is sufficient to support heavy locomotives, it may be taken as sufficient for street railway motors where the ground is good. In conclusion, it may be remarked that the tendency of the best practice is to dispense with all timber underground. A wooden cross-tie under a steel rail and granite pavement, is as much out of place as would be a foundation of crib-work under a handsome house of dressed ashlar.

The Rail Supports.

The timber system of stringers resting on cross-ties to which they are fastened by cast-iron knees, is too well known to need description. It forms a striking contrast from the most advanced practice in England at the present, where the rail has no intermediate support whatever. Weighing, as it does, from 100 to 120 pounds to the yard, it rests upon a longitudinal bed of concrete which covers its flanges and maintains it absolutely immovable. It requires no tie-rods even on curves, and in renewing it the pavement need not be disturbed beyond the width of the base of the rails—6 or 7 inches. When taking maintenance and renewals into account, this method is cheaper in the long run than the wooden stringer, especially where the street is paved with granite. If companies using timber could be induced to give the cost per mile of repairs, carried out as they are, piece by piece, as trouble arises, it would probably account for the excessive "working expenses," so-called, which have placed many of them into the hands of a receiver. On the other hand, this huge self-supporting rail cannot be called economical. Supposing the head, which is the only wearing surface, to have a life of seven years, it will then have lost in one yard's length about 5 or 6 pounds of iron by attrition, and since it weighs 120 pounds, about 94

to 96 per cent. of the section, perfectly unworn, will have to go to the scrap heap.

This is a startling change from the parent tramway of Coalbrookdale, where a century ago the Coalbrookdale Iron Company laid down upon wooden stringers their surplus stock in slabs, still treasuring them as an asset, to be used up when they ran short.

The Goliath girder-rail is not, however, the first attempt at a self-supporting way, and the following system, though not extensively used, is well deserving of notice, because it was the first to present the element of a maximum stability:

The Deas and Rapier System.

As early as 1870 the tramway already referred to was laid in Glasgow, Scotland, by Mr. Deas, engineer to the Clyde trustees, in which the rail formed the upper portion of a cast-iron box filled with concrete, and resting upon a lower bed of concrete. The wearing parts were chilled, and stood the heaviest traffic of the wharves of the city very successfully. The sides formed a vertical wall to the paving, and the concrete, being laid in a longitudinal pit, made comparatively little disturbance of the road surface. The boxes were cast in 5 feet lengths, filled bottom upwards, and then lowered into place with tackle. Tie-rods were at first used, but afterwards abandoned as unnecessary. The blocks remained perfectly stable by their own inertia. The disadvantages of the system were:

First.—The blocks were heavy to handle.

Second.—The concrete having set in, the boxes did not form a bond with the bottom layer.

Third.—In order to renew the track, the whole cast-iron box, 90 per cent of which was unworn, had to be sacrificed, together with its filling of concrete.

The great width of rail surface was adopted in order to enable the company's drays to use it equally with the flanged car wheels. The material used was evidently in excess of the actual requirements, because there was ample support to the rail in the internal concrete, without bringing down continuous heavy metallic sides. It is also evident that the arrangement of the material in the double web form, instead of in one central web, should not lead to extravagance but to economy of material. The girder form of rail or flanged tee-rail, as it

should be more properly called, requires a thickness of web not only sufficient to resist the direct static stresses developed within it by the load, but also to resist the torsional stresses produced by its comparatively low stability. The box girder or twin web by its geometrical form possesses so much greater stability, that it can afford, with the same weight per yard forward, to let some of its material go to an increase of depth, and so form not only a stiffer but a stronger rail, especially when the space between the web is occupied by a filling which precludes the possibility of buckling of the web. The stability in the Deas rail arose from the weight of the cast-iron and enclosed concrete, assisted by the adjacent paving, but as there was no bond with the lower concrete, this was all. The support of the adjacent pavement is not an easy thing to calculate, and considering that it is sometimes removed during traffic, it is safer not to make any allowance for it.

Comparing the stability of a 5 feet length of the Deas pavement with and without cohesion of the upper and lower concrete, we will assume the concrete to have been made of 1 of cement to 5 of gravel, the box being 10 inches wide by 8¼ inches deep, 203 pounds per yard.

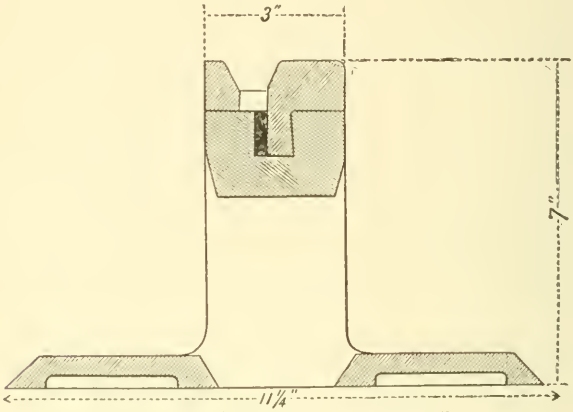
Without any cohesion the force applied at rail level necessary to overturn the block would be 349 pounds. Properly bonded, at the end of a week, the force necessary would be 12 600 pounds. At the end of a month it would be 18 350 pounds.

These figures go to prove that if the concrete were made to cohere, the only disturbing force would be one sufficient to overturn the whole structure with its foundations, or to force it sideways through the paving, and, consequently, how easily a vastly increased stability, even with a much narrower box, might have been obtained.

Mackison's Way.

An improvement upon the Deas system is seen in the Dundee tramway of 1880. The cast-iron box with close sides is replaced by a series of nearly continuous open-framed boxes 3 feet 11 inches long, laid in line under each rail. The spaces between the standards of the frame are packed with concrete from the sides and ends, but both the top and bottom are continuous plates, the lower one 11¼ inches wide and the upper 3 inches wide. The rail is of the grooved central web type, having longitudinal slots cut through the floor of the groove, into which wrought-iron keys are inserted and driven up against the center web.

This latter is rolled with a taper, and is retained in place by the keys. They can be struck and the rail removed without disturbing the pavement. The spaces in the slots between the wedges are filled with asphalt. The whole width of track and somewhat outside of it rests upon a bed of concrete 6 inches deep. The best features of this system appear to be the concrete foundation, the continuous support, and the



MACKISON'S RAIL AND SUPPORT.

Fig. 2.

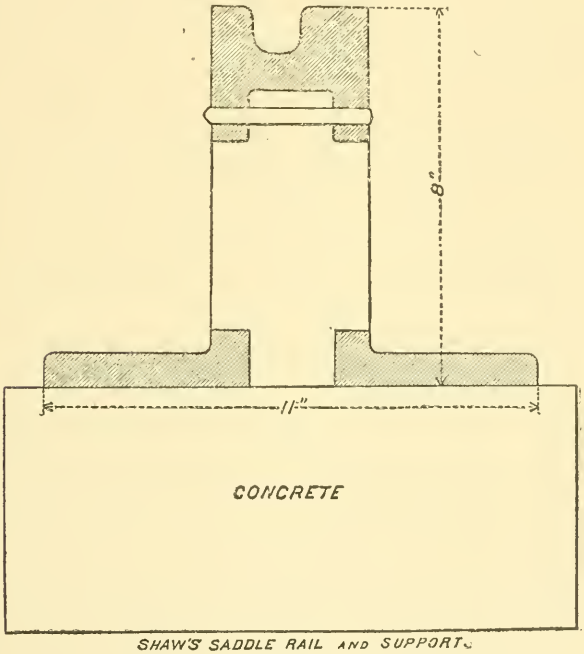
removable rail. The cutting of a slot, on the other hand, must be deemed a drawback to the rail, and the central web not being required for transverse stress, can only be regarded as a means of attachment, and, similarly to the Deacon rail, involves a considerable amount of superfluous material between the attachments.

Quantities and Cost at American average Prices of Mackison's System for One Mile of Single Track.

Steel rails, 36 pounds per yard, 56½ tons, at $44.80	$2 531 20
Wrought-iron keys, 2 170 pounds, at six cents	130 20
Cast-iron stringers, 141½ tons, $33.60	4 753 40
Lifting and carting away macadam, 522 cubic yards, at fifty cents	262 00
Excavation, 1 108 cubic yards, fifty cents	554 00
Concrete, 6 inches thick, 782 cubic yards, $5	3 910 00
Laying track, 1 760 lineal yards, sixty cents	1 056 00
Royalty	365 00
Total for the way, exclusive of paving	$13 561 80

The Shaw System.

Shaw's system at Manchester, Eng., consists of a saddle rail resembling the Lewis & Fowler (Fig. 17), but instead of isolated chairs a continuous, or nearly continuous, cast-iron stringer supports the rail. The stringers are 4 feet 11 inches long, and are laid 1 inch apart longitudinally. They weigh 117 pounds each. The rail, 45 pounds in weight, is of the ordinary box or saddle section attached by the side flanges with



SHAW'S SADDLE RAIL AND SUPPORT.

Fig. 3.

spikes driven through hardwood plugs. The bottom beds of concrete are 15 inches wide by 5 inches deep, and concrete is packed up sideways under the rail so as to form a wall to the paving. The combined weight of rail and casting make 116 pounds of iron per lineal yard.

QUANTITIES AND COST AT AMERICAN AVERAGE PRICES OF SHAW'S SYSTEM FOR ONE MILE OF SINGLE TRACK.

Steel rails, 45 pounds per yard, 70 tons, at $44.80....	$3 136 00
Cast-iron stringers, 70 pounds per yard, 110 tons, at $36 60.....	3 696 00
Spokes, 1 570 pounds, at four cents.....	62 80
Wooden plugs. 6 160, at one cent.....	61 60
Concrete, 204 cubic yards, at $5.....	1 020 00
Surface excavation, 8 inches deep, 1 109 cubic yards, at fifty cents	554 50
Total cost of way, exclusive of paving.....	$8 530 90

The amount of concrete depends upon the nature of the ground. If the same quantity of concrete were used as in Mackison's system, it would bring up the cost to $11 420 per mile.

In both the Shaw and Mackison systems, there is little or no cohesion between the concrete packed into the stringer and the bottom bed; they are separated by the bottom plate of the stringer. The concrete filling has to be packed in from the sides, which is a difficult matter to do satisfactorily.

The advisability of a continuous or an intermittent support to the rail, depends upon the character of the road and the condition of the ground. The wooden stringer offers a continuous support, and works well as long as it lasts. It is economical, because the flat rail carried by it is cheaper than the girder-rail. The girder-rail, with intermittent supports, is coming more into favor in this country, whilst the same class of rail is laid in England on a continnous bed of concrete. The paving blocks in England are not so deep as in America. There the average is 7 inches deep. A great deal of heavy traffic is carried on 6-inch blocks, and probably 7½ inches is the deepest, whereas here the blocks run 9, 9½ and even 9¾ inches deep. A rail 10 inches deep would be too extravagant, therefore the use of chairs of cast-iron, wrought iron or steel to keep it off the paving. It cannot be claimed for the principle of intermittent supports that it is needed to produce elasticity, because perfectly rigid tracks like many of those in England, wear just as well as those having elasticity, and they wear the paving less. A very elastic street track will soon shake up the adjacent paving and cause its rapid destruction.

Chairs are usually set upon wooden cross-ties in this country, the objections to which have already been referred to. Probably before long

they will give place to metallic cross-ties, which are already in the market. Mr. Tratman's paper takes up this subject, but it may be added that steel ties for tramways and light railways in British colonies are being largely manufactured in England. They have no chair, but the rail is attached direct to the tie by its flanges. The ties are stamped out of mild steel plate by a machine furnished with a punching die, which leaves a lug to catch one flange and a bolt-hole opposite it to receive a clip-bolt for the other flange. The Indian State railways use mostly a tie with a reversed vertical curvature, so as to form a kind of bridge in itself, and with flared sides, but for smaller railways plain channels are used. Several types of these are made by the Johnson Company; one of them is made out of a pair of angle irons connected by short plates, so as to leave an opening lengthwise for tamping the ballast.

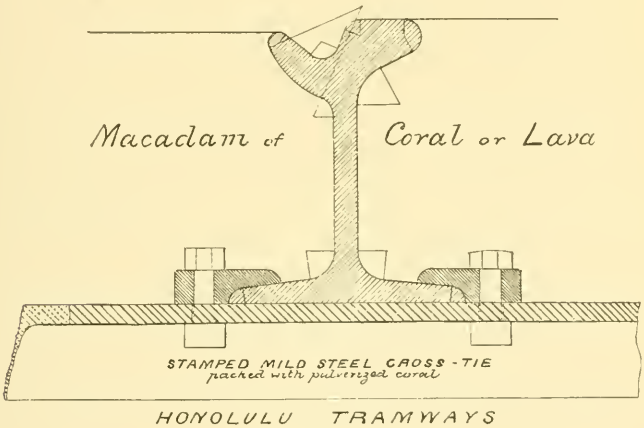


Fig. 4.

The rail illustrated in Fig. 4 was used by the author upon the 12-mile tramway of the City of Honolulu. An unreasonably rigorous stipulation in the franchise called for a flush surface inside and outside of the track, although no paving material was procurable within 2 000 miles. Timber decays in that climate in from one to three years. The girder-rail was adopted with as easy a groove as permissible, bolted by its flange to mild steel cross-ties, packed with pulverized coral. Cement concrete was first used until it was found that the coral made as good a packing. The road was macadamized with either coral or hard lava-rock, rolled down after the track was laid by a 15-ton steam roller which

produced no settlement upon the track. To prevent the stone being crushed into and wedging up the groove when being rolled, it was filled half full of volcanic sand and then covered with loam, which formed a very hard crust over it under the roller. This filling resisted the tropical rains and all the vehicle traffic for several months until the line was ready for opening, but was easily removed when required for use by a man with a pick, who cracked the crust and ripped out the filling almost as fast as he could walk. This furnishes the idea for a protected lug or key-seat in the suggested system to be described later on.

Chairs are made of cast-iron, mitis steel, or drop-forgings. Cast-iron chairs have fallen into great disfavor here on account of their liability to breakage in spiking. They are still in general use on trunk lines in England, where, for spiking, a hollow "trenail" of compressed wood, generally oak, is sometimes driven into a hole bored in the tie, and a cylindrical spike or drift-bolt then driven through so as to force the fiber of the trenail into that of the tie and form a perfectly tight and very durable fastening. With metallic ties, cast-iron chairs are not objectionable, except on the ground of difficulty in securing a perfect fit to the flange of the rail. The Johnson Company make a mitis steel chair which supports the rail in a very thorough manner, fitting it under both sides of the head and both edges of the flange, and is keyed up tight by a cast wedge having a splice-bar fit.

The use of this valuable material, mitis iron and steel, will probably be extended by the reduction in price of aluminium, and be largely used in rail fastenings. It is perfectly malleable, though not rendered so by the old process of annealing. It is an excessively mild steel, having the properties of wrought-iron in greater or less degree, according to the proportion of high grade iron in the mixture.

The drop-forged chair in common use for merely holding the flanges of the rail, has a pair of lugs at opposite ends, so that by twisting the chair sideways it can be inserted under the rail, and then by twisting it square the lugs are brought to bear upon the flange. When this chair rests on a wooden tie, the loosening of the spikes will be liable also to loosen the hold of the lugs.

A chair with one lug and a bolt and small clip opposite to it for holding a flange rail, occupies a little more time in attachment, but is more satisfactory, as being independent of the lower fastening to the tie.

Other chairs are made to fit the web of the rail as well as the flange,

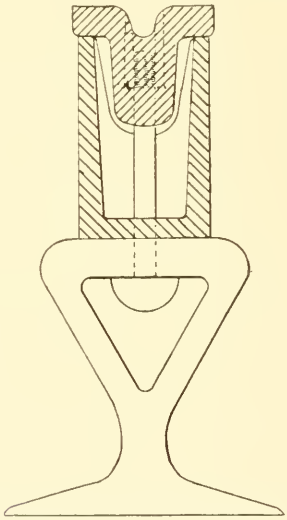
and are called brace-chairs. The chair proper is a flanged channel under the base of the rail, from the side of which a clip is carried around the flange of the rail and up the web on one side, whilst a cast-iron clip is bolted in to the other. It will be observed that there is no bolt through the web of the rail to hold the clips up against it. The chairs are intended to be placed at any part of the rail, so that a through bolt would be impracticable, but in the absence of them there cannot be a very strong hold upon the web of the rail. In the case of the flangeless tee-headed rail, however, the Johnson Company use a complete splice-bar fit with a through bolt. This involves piercing the rail wherever a chair occurs, but is obviously needed in order to obtain a good hold upon the rail.

An improvement in construction is to be found in the Lewis and Fowler chair. It arises from the prior improvement in the form of the rail. Without forestalling the subject of rails, it will be noticed that the adoption of the double-webbed rail, at once admits of a form of chair which has greater inherent stability. A distance-piece inside the chair keeps the sides apart, whilst the two bolts draw up the sides of the rail against the chair, by an elongated jaw-washer, which holds a lip on the rail down to a lip on the chair. The vertical stress of the car wheel at the joint passes directly to the chair, and through the chair to the tie, the jaw-washer is not intended to perform the duty of a splice bar, it merely acts as a fastening. The chair is itself a bridge and an abutment in one, having the whole depth available for construction with which to resist deflection. There appears, however, to be no connection between the upper portions of the chair under the rail. These flanges would, therefore, possess but little strength, and might be dispensed with in their present form. In the Johnson chair the depth available is from the base of the rail to the tie. There is on the one side a clip, which completely surrounds the rail and must be exceedingly carefully fitted as shown in Fig. 15, on the other side there is a channel splice-bar, slightly bridged in order to give grip to the four bolts. The company lay great stress upon the splice-bar fit, but the use of a supported joint as shown, is an evidence against the sufficiency of the splice-bar. A stress which is carried by a splice-bar puts the latter into transverse strain at the joint; producing longitudinal stresses of compression in the upper and tension in the lower extremity, consequently a deflection, more or less, of the rail at the joint. The bolts being approximately at the neutral axis are not materially affected.

With a supported joint upon a chair of the form shown, the stress passes directly through the chair to the tie, and being much stiffer than the splice-bar, the chair will carry nearly all the stress. It would appear possible in the Lewis & Fowler chair to form an alliance for mutual support between the upper ends of the chair, as shown in Fig. 17, and so to entirely underpin the rail, whereas in the Johnson joint, the free ends of the clip and splice-bar, unless the rail is pierced, afford an inconsiderable support to the rail as compared with the amount of material in them.

The Deacon System at Liverpool, England.

In the Deacon system, at Liverpool, Eng., a grooved, reversible rail was used, resting on a continuous cast-iron box, to which it was bolted at its center. A greater proportion of the iron was here made effective for wear and the vertical wall for the paving was preserved.



DEACON'S REMOVABLE RAIL

Fig. 5.

Having no internal concrete, the box lacked the stability of the Deas system, and required to be supported on wide iron chairs. The central bolt attachment was made by screwing down a phosphor bronze nut and surrounding it with red lead. Consequently the rail had to be

much deeper than was needed for actual wear. Mr. Deacon laid great stress upon the fact of the permanency of his cast-iron box, and its forming a suitable wall for the paving. The attachment was found satisfactory, one man with a chisel-pointed wrench was able to put a pull of 2 tons upon the bolt, which was slot-headed, and the nut-chamber was kept free from corrosion by a filling of plastic pitch. The rail was not intended to be reversed, but to be used with car wheels having central flanges and double treads. The rail, in itself, has sufficient material to carry a load between intermittent supports, although it rests upon the casting throughout. The great bulk of the central portion was to give covering over the nut, and the rails had to be drilled and the chamber turned out so as exactly to fit the bolts in the casting. One would think that a slight mistake in the spacing might produce great expense and inconvenience.

The Rail Material.

Cast-iron is not now used for rails. Probably the only and the last tramway laid with a cast-iron rolling surface was the Glasgow system of Mr. Deas. It was satisfactory in point of durability because in it a surface of very great hardness, chilled cast-iron, not under transverse stress, was placed in suitable conditions for service as a rail. The disadvantages of that system have already been touched upon, but it remains as a suggestive illustration of the fact that in positions where an elastic girder under transverse stress is not required, a material may be used which is better adapted for resisting attrition than the usual mild steel employed in rails.

By tempering or case-hardening steel, a surface may be obtained which is three times harder than ordinary mild steel, but without tempering, the amount of carbon used in the making of the steel will vary its hardness 100 per cent.

The steel usually adopted for street railways is similar to that for larger railways, and the specifications generally call for about .25 to .30 per cent. of carbon with hot-bending and cold-bending tests for tensile strength, elongation and ductility, as stringent in every respect as those of the best trunk lines.

It is, however, a perfectly different treatment of the steel to support it as a flat rail continuously, from what it receives under the conditions of an ordinary railway. The life of rails shows this when compared under varying speed of travel. A rail only under slowly rolling loads

will possess two or three times longer life in tonnage than one subjected to high speed engines. It is the shock that tells. At the moderate speeds permissible upon city and suburban lines, upon a continuously supported rail, there is no transverse stress and no danger of breaking a rail. Nothing but a rubbing down of the surface, which may be made as hard and brittle as tool steel without any danger.

Tool steel has a percentage of 0.6 to 1.2 of carbon, and its hardness is double to treble that of rail steel. The view is here submitted, that the life of street railway track might be doubled without any danger of accident and with little extra cost. As an illustration, the tongues of movable switches, being under concentrated shocks on thin edges, are made of shear steel of great hardness, but being continuously supported, are quite safe.

In the streets of a busy thoroughfare, the rails are worn nearly as much by the vehicles as by the car wheel. The following series of worn sections will show this very clearly, and also the comparatively small difference between the wear of the iron and steel. They exhibit the wear due to traffic in the City of Glasgow on two of the busiest thoroughfares, one on the north and the other on the south side of the River Clyde. The first pair of rails were down six years and five months, and the second pair six years.

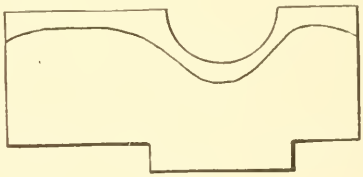


FIG. 6.

Iron rail in wear for six years and five months; original weight, 60 pounds per yard. Lost 0.858 pounds per yard per annum.

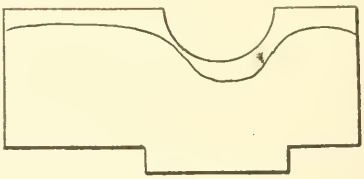


FIG. 7.

Steel rail in wear for six years and five months; original weight, 60 pounds per yard. Lost 0.849 pounds per yard per annum.

These diagrams were taken from Mr. Clark's standard work on "Tramways," who gives the original sections and the worn sections separately. In superimposing them as shown, to exhibit the wear graphically, the amount of wear does not correspond exactly with the numerical results, but will serve to give a general idea of a matter, which must vary much according to the nature of the traffic and the composition of the rail. There are unfortunately no data of the relative chemical composition of these rails, but seeing that they were alike continuously supported, it would appear that the ratio of wear was identical with the ratio of hardness.

The wear of steel rails on larger railways is also unsatisfactory, considering the possibilities of that material. Allowing for great differences of opinion amongst engineers, arising from different conditions of speed,

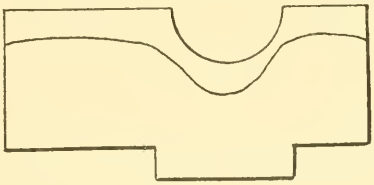


FIG. 8.

Iron rail in wear for six years ; original weight, 60 pounds per yard. Lost 0.811 pounds per yard per annum.

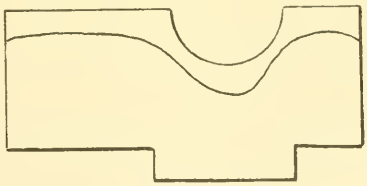


FIG. 9.

Steel rail in wear for six years; original weight, 60 ponnds per yard. Lost 0.689 pounds per yard per annum.

spacing of cross-ties and ballasting, giving sometimes very conflicting results; the fact remains that hard steel rails do not realize the durability under heavy traffic which their hardness would lead us to expect.

At the meeting of April 6th, 1874, of the Inst. C. E., in London, many valuable data were produced upon this matter. Mr. Josiah Tim-

mis Smith gave the results of tests on rails manufactured at Barrow, weighing originally 73 pounds per yard, and in wear under heavy traffic for eight years. Twenty mild steel rails, having a percentage of carbon of from 0.28 to 0.30, lost a percentage of weight averaging 13.54. Ten hard steel rails, having a percentage of carbon of from 0.36 to 0.57, lost a percentage of weight of 15.18.

Mr. Harrison, President of that year, exhibited specimens of steel rails of average hardness, which had stood seven years of the heaviest traffic on the North Eastern Railway, with a loss of 10.6 per cent., and in contrast with this, a pair of iron rails case-hardened to a very high degree by Dodd's process, which under fifteen years heavy traffic had lost only 2.6 per cent. The reason why these latter rails were not used exclusively was not the cost of the process, which was only £1 per ton, but on account of the frequent breakages from their brittleness. It remains as a valuable illustration of the possibilities of iron or steel, when applied in a manner calculated to utilize without danger all the hardness that can be put into them.

The drilling or punching of holes in the web of the rail for splice-bars, or the cutting of notches in the flange for spiking, has been proved to be very detrimental to its strength. Experiments recorded by Mr. William Hackney, of the Landore-Siemens Company, show that under the drop test a piece of rail with no holes stood a blow of 1 ton falling 20 feet, whilst another piece of the same rail with a punched hole through the web, broke under the first blow at a 3-foot fall, and a piece with a drilled hole of the same size stood the first blow at 2 feet, but broke with the second at 4 feet. He sums up his experiments with the remark:

"If rails could be firmly fixed down without cutting holes or notches in them * * * they would either be so much stronger that breakages would be unheard of, or they might be made of hard steel so as to be more durable, or of an inferior quality of steel, so as to be lower in cost."

Mr. Sandberg's experiments on the strength of steel rails with notched flanges, show a loss in common iron of 30 per cent., in hard iron of 50 per cent., and steel of 80 per cent. of strength.

As long as it is considered unavoidable to adhere to the present form of support, some form of interference with the integrity of the rail section is unavoidable, but it cannot be called a satisfactory expedient

either as regards safety under shocks or gradual wear—in regard to which latter point a brief investigation will be made.

When a hard substance wears no longer than a soft one, the reason must be sought for in the manner of wear. When a steel rail which would resist a file double the time of another rail, resists the locomotive wheel no longer, it is plain that friction alone is not responsible. There must be forces at work arising out of the manner of application of the load, which greatly assist the abrasive action. In a rail with intermit-

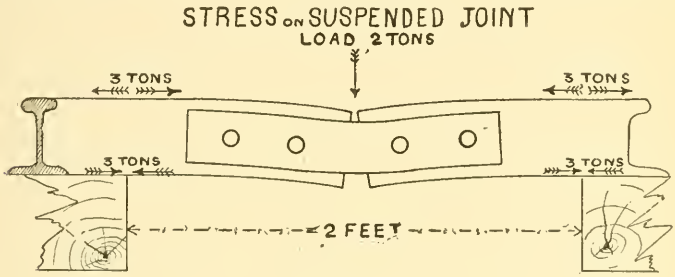


FIG. 10.

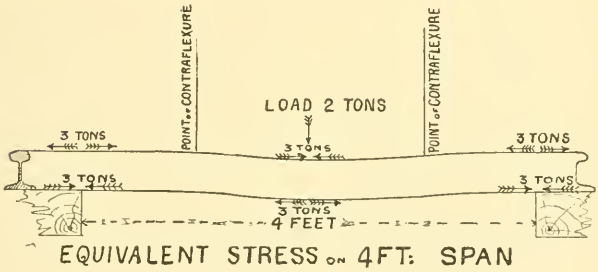


FIG. 10A.

tent supports, there are three distinct forces operating immediately under a heavily loaded wheel when it is midway between the cross-ties.

First.—A horizontal compressive stress. *Second.*—A vertical blow. *Third.*—A rub.

They resemble the squeezing of a man's body by head and toes, and without giving him a chance to expand sideways, punching him in the ribs. Add to this a species of "massage" treatment by the parting driver, and we have a diagnosis of the rail-trouble.

When an English double-headed rail is reversed, it is found that the wearing head is not only abraded, but crystallized, and unfit for sustain-

ing any tension. It is claimed that such worn rails can be made reliable only by planing off the crystallized portion, after which the worn head will do duty as a tension member, and the new head never shows any signs of fatigue from its former duty as a tension member.

As a matter of fact, the reversibility of a rail is not of much value under those circumstances.

A rail, Fig. 10, 4 inches deep on a 4-foot bearing and loaded in its center with 2 tons, will be under a horizontal compressive stress of 3 tons in the head. Independently of this, a vertical force due to impact, varying in its intensity directly as the elasticity of the rail and inversely as the elasticity of the springs, will act upon it with a possible force of

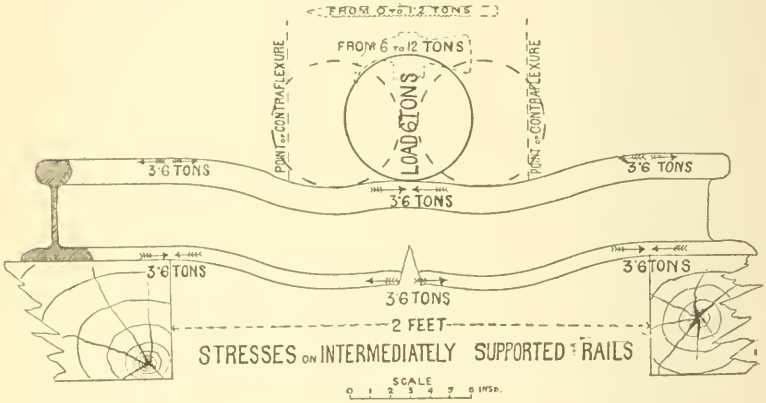


FIG. 11.

4 tons. Thirdly, the abrasive force of friction may be anything from a few pounds to half a ton.

This simultaneous action of forces may be illustrated by supposing them increased so as to destroy the rail, which would then be deflected, as shown on Fig. 11, which represents a heavy locomotive wheel on a heavy rail. The lower fiber has parted and the upper fiber has bulged. The wheel acting as a hammer upon the bulged fiber quashes it, and when leaving it, acts like a file and rubs it off.

It is probable that the molecular action of fatigue, which is most severe under alternating stresses or simultaneously applied diverse stresses, is analogous with the action of destruction shown on Fig. 11. Although the fiber may not bulge, the particles in the upper surface are pressed together with great force, thus assisting the abrasive action.

When passing on a rapidly moving train from a worn and badly kept piece of track to a newly laid section, the rhythmic measure of the car wheels is suddenly exchanged for a steady roll, showing that the wear of the old track has been intermittent like the supports.

The proposed "Sayre" rail, illustrated in Mr. Tratman's paper, shows a marked increase in the depth of the head, probably to meet these concentrated forces; whilst Mr. Sandberg's Goliath rail has greater width. Deepening the head brings the neutral axis further up the section, and renders the lower portion of the head of little value in resisting the compressive horizontal stress. Statically considered, the wide head makes a more efficient girder than the deep one.

The rapid wear of rails upon rigid intermediate supports, such as chairs, may be illustrated by the following exaggerated diagrams. In

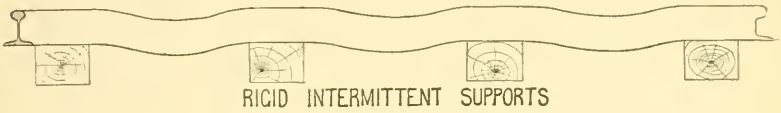


Fig. 12.

the first case, Fig. 12, there is a sharp and contrary curvature between each pair of supports, whereas, when the supports are flexible and yield somewhat to the load, a gradual curvature is formed, which makes a less demand upon the ductility of the rail.

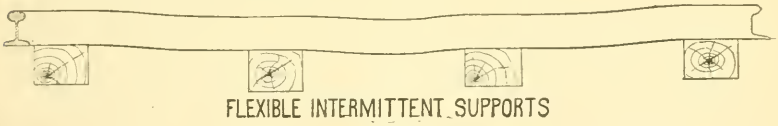


Fig. 13.

A continuous support on the other hand may be quite rigid under high rates of speed. On the Great Western Railway of England, trains run at 60 miles an hour over a bridge rail resting on a longitudinal wooden sleeper, which is bedded upon about 2 feet of stone ballast. It makes a very economical track as regards the rail, because a light section is used to carry the heaviest traffic. It is also a safe track, because there are no bolt holes in the rail and no danger of breakages. The company maintains the system on the main lines, but the branches are laid with cross-ties, the reasons being the higher price of timber for longitudinals, and the disadvantage of having to remove the rail when renewing the sleeper.

The Rail Section.

The rails in use at the present time, or which have been used with any degree of success, may be classified as follows:

First.—The tee-rail, with flanges, or Vignoles rail.

Second.—The girder-rail or Vignoles rail, with groove or tram.

Third.—The tee-rail, without flanges.

Fourth.—The box-rail.

Fifth.—The flat rail.

The common tee-rail has been considered in Mr. Tratman's paper, and will not be dwelt upon in this paper, except to compare it later on with the box-girder principle. It is an easy rail to run on, and where city authorities permit it, the tramway company may consider itself lucky. Generally, if allowed at all, it is only on sufferance in partially developed suburbs, and the company is sometimes compelled to replace it with a different type earlier than they expected.

With regard to the girder-rail, with or without bottom flanges, quite a number of designs have been tried and are still in the market. They differ not only in outward form, but in their essential properties of strength and stiffness. It would seem as if their designers did not always make the theoretical perfectness of the rail the starting point, since so much of the section is designed merely to make a suitable attachment, as, for instance, in the Deacon rail (Fig. 5). The street rail cannot maintain the same symmetry of figure and theoretical perfectness of the railway rail, but it can approximate to it very closely. Two essential points about a girder-rail when laid against paving, are that:

1. The vertical stiffness or resistance to deflection is of prior importance to its strength.

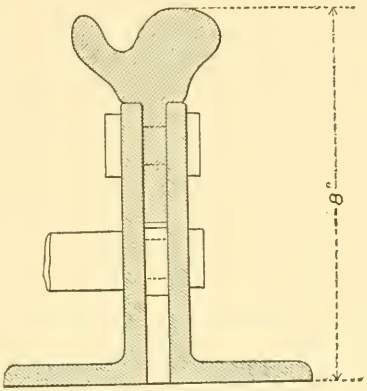
2. The torsional stability of a rail cannot be efficiently supplied by vertical depth of attachment; it needs lateral width in order to give moment of resistance.

Two rails of the flange and flangeless type will be presently compared as to these points, but a word of introduction may be prefaced to supply the history.

The flangeless tee-rail seems to have made its first appearance in 1870 in the Cockburn-Muir system at Montevideo, where it was laid on longitudinal cast-iron sleepers, about 12 inches long, and about 3 feet 6 inches apart from center to center. It was followed by the Barker

system at Manchester in 1877. There the shank of the rail was housed in the chairs by a close-fitting joint and fastened transversely by a gib and cotter.*

The Meakins rail (Fig. 14) in South London, laid in 1880, consisted of a flangeless tee weighing 52 pounds per yard, sandwiched between a pair of angle irons, making up the total weight per yard forward to 112 pounds.



MEAKIN'S RAIL.

FIG. 14.

Although distinct from its support, the rail was not designed to be renewable separately, being attached to the angle irons by ¾-inch rivets, at 6-inch pitch.

The Deacon rail already alluded to, also resembles a flangeless tee. It was laid in 1877–78.

The Johnson Company of Johnstown, Pa., has introduced a bulb tee, which is not only an improvement on the flangeless tee as regards the fastening, but makes a much stronger rail. It is still, however, far behind the flanged girder-rail. The following comparison of two rails in their catalogue will show in a striking manner the loss that a girder sustains, by robbing it of its "understandings":

No. 131 (Fig. 15) is a 78-pound rail with tram head and bulb foot.

No. 207 (Fig. 16) is an 80-pound rail with groove head and flange foot, reduced to a 78-pound section by slightly narrowing the bottom flange. It is 0.8 centimeter longer.

In the bulb-rail, the neutral axis is almost in the head itself, so that

* For cuts of these, see discussion by Mr. Gribble.

the mass of iron forming the tram of the rail furnishes very slight resistance. Moreover, the center of gravity is not midway in the web, but at the extreme right, thus giving it an inherent disposition to cant. The flange-rail has its center of gravity in its center of figure, that is to say, it bisects the rail lengthways and breadthways, or nearly so. The bulb-rail has a moment of inertia of 835 centimeters, and the flange-rail 1 603. Comparing the former figure with the deflection under proof-load recorded in the catalogue. A load of 62 000 pounds applied on a 24-inch span, produced a deflection of 0.027 inch. Assuming the load to have been applied in the center and the ends supported but not fixed, a moment of inertia of 835 centimeters would correspond with a modulus of elasticity of 32 965 000 pounds, which is a good average for rail-steel, and checks the computation.

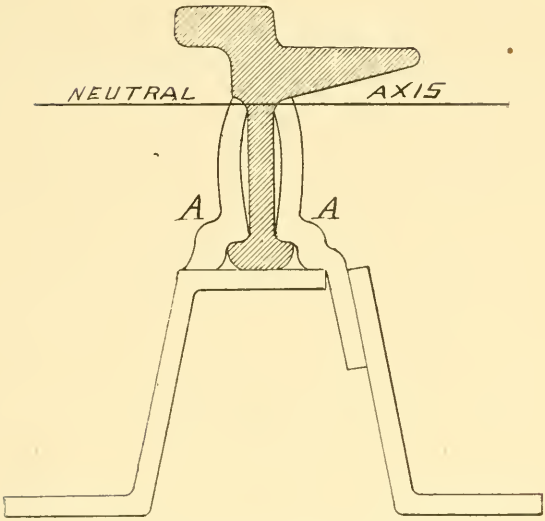
Tests of the flange-rail are not recorded, but with the same modulus it would have a deflection under similar conditions of loading of 0.014 inch, or about 52 per cent. of that of the bulb-rail.

As regards stability, when fastened to a chair, the bulb-rail has only the stability due to the resistance to bending of the plate at the throat marked *A*, and the perfectness of the fit of the bolts. The flange-rail has inherent stability. In order to cant, it must rotate upon one of its flanges, and in so doing lift either the clip or the brace which opposes a resistance having a leverage of nearly the width of the base of the rail.

The second condition, previously mentioned, of an unyielding rolling surface, is only fulfilled thoroughly by a continuous support; but where an intermittent support is used, the flange girder-rail is always more efficient, and consequently more economical than the flangeless tee or the bulb-rail.

The fourth type of rail, termed usually the box-rail, has formed the subject of numerous ancient and modern patents. Whilst treating of the rail supports of the Lewis & Fowler rail, it has been pointed out how the double-webbed rail affords increased stability with the same amount of material.

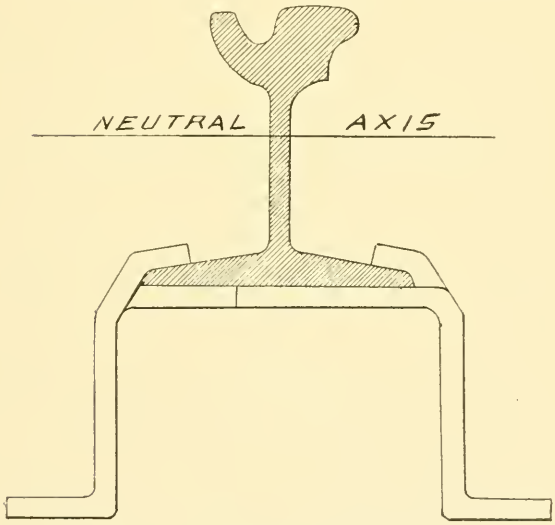
The earliest types of box-rail will only receive a passing comment. In some cases, the two webs form part of the rail, in others they are distinct rails, but fastened together. The first approach to the box-rail was the Larsen saddle-rail, at Dublin, which had a continuous support, its form being selected to substitute a side fastening for a central one, its stiffness, however, demonstrated the practicability of its being intermittently supported.



JOHNSON BULB-RAIL & CHAIR

FIG. 15.

Weight per yard (rail only) 78 lbs. Moment of Inertia 835 c. m.



JOHNSON FLANGE-RAIL & CHAIR.

FIG. 16.

Weight per yard (rail only) 78 lbs. Moment of Inertia 1 603 c. m.

The tramways of Lille were laid with a twin rail having a cast-iron distance piece. The wearing rail being bull-headed, and the other a similar rail, but only having half a head, it acted like the guard rail on steam railways.

The Lewis & Fowler and the Gibbon rails are the two most recent forms of the box-rail.

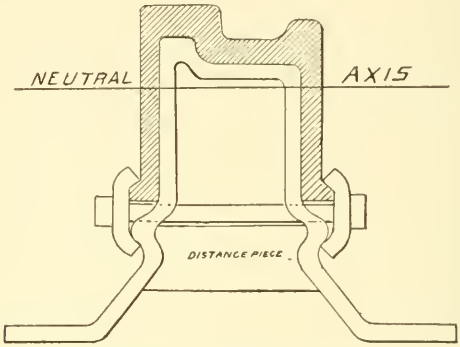


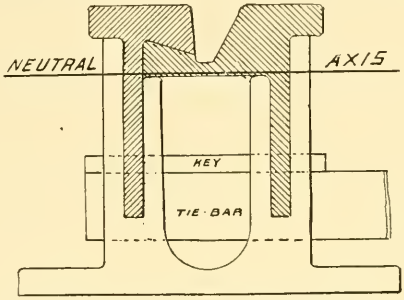
FIG. 17.

Weight per yard (rail only) 78 lbs. Moment of Inertia 1 227 c. m.

In the Lewis & Fowler rail (Fig. 17) the webs form part of the rail itself, consequently have greater strength than when divided.

In the Gibbon duplex rail (Fig. 18) one web supports the wearing head, and is removable. The other supports the tram. The attachment is by spring wedges, and without much disturbance of the pavement, the worn portion can be removed and a fresh one replaced. Here is a decided step in economy where there is not heavy vehicular traffic. It is proved, however, that in crowded thoroughfares subject to dray traffic, the entire rail surface wears equally, and the advantage of division in the rail would be little or nothing. Both rails have considerable stability of figure, and the Gibbon rail appears to be the only one which possesses an attachment without bolts. Both the Lewis & Fowler and the Gibbon attachments are excellent, the only drawback to them being, that some of the paving must be removed in order to get at them. Neither of these systems has any tension-flange to the rail, consequently the same criticism that was applied to the flangeless girder-rail is also applicable to them in greater or less measure; but when, as pointed out

at the commencement, from 90 to 95 per cent. of unworn girder-rail is doomed to the scrap heap, any device, such as the Gibbon, which can materially diminish this great waste deserves serious attention.



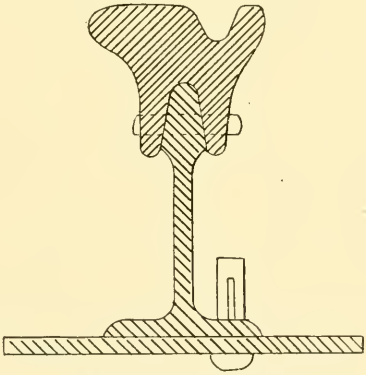
GIBBON'S DUPLEX GIRDER RAIL AND CHAIR

FIG. 18.

Weight per yard (rail only) 78 lbs. Moment of Inertia 811 c. m.

Both the Lewis & Fowler (Fig. 17) and the Gibbon system (Fig. 18), the former especially, give a good wall to the pavement which the girder-rail does not. The moment of inertia of the 78-pound Gibbon rail is 811 and that of the Lewis & Fowler 1 227 centimeters.*

The Page rail used on the North Metropolitan tramways in London is a further step in economy. It is a modification of the girder type, in



PAGE'S REMOVABLE RAIL

FIG. 19.

which the wearing head is removable, having a longitudinal recess or mortise into which the upper part of the web fits and is wedged up

* See discussion on this point.

with cotters. This attachment has the appearance of great weakness, but the principle might be conserved with a stronger attachment by deepening the recess sufficiently to admit of a double row of wedges which might be zigzagged.

Flat Rails.

The original type of flat rail consisted of a broad wearing head, with a shallow step, and a broad tram; it was rolled in sections weighing from 30 to 60 pounds per yard, and attached to the wooden stringer by spikes through the middle of the tram. In the heavier sections an attempt was made to lighten the head by hollowing it, but it was found that the rail worked its way into the timber.

When upon a continuous metallic support, the flat rail need not be much heavier than the amount of wear allowed for. That is to say, supposing the full wear of a rail to be ¼-inch, the rail should be about ½-inch thick, so that by the time the car wheel begins to run on its flange there will still be about ¼-inch left at the time of removal. The various modifications in the form of the head, such as side-bearing, etc., will be considered as part of the subject of rolling surface. Although every rail not provided with a vertical web is termed a flat rail, some of the types are anything but flat.

Economy of Renewal.

The aim of the street railway company for its own sake as well as that of the public, is to have a track which will wear well. Unfortunately, it has often to take in hand a contractor's line, one built on speculation, not by those who propose to work, but by those who desire to sell it at a large profit on their outlay. Consequently, whilst it may provide showy cars and perhaps electric motors, the track, being so much of it underground, is the least valuable part of the assets. Frequently a system, doing a large business and with good prospects, finds itself at the end of two or three years in a bankrupt condition because the whole of the roadbed requires renewal. A track which has cost $15 000 per mile, including paving, renewed at the end of three years, will cost sometimes $12 000 a mile, although the pavement is but little worn. The wooden cross-ties being decayed require the removing of the whole pavement, which with relaying, is equal to from a third to half the original cost of paving. In order to keep out of financial

trouble, a company possessing such a roadbed ought to write off from revenue a reserve fund of $4 000 per mile per annum, to meet a renewal at the end of three years.

No company, however, would care to confess to having a track of triennial periodicity, it therefore generally pays as good a dividend as possible out of all it earns, and hopes for some new revelation of electric science by which it will be able to reorganize like a butterfly from its chrysalis.

In the Mackison way with good rails and materials of foundation, the renewal say, at the end of seven years, of 1 mile would be, for

Rails	$2 531 20
Removing and refixing ditto, say	440 00
Total	$2 971 20

One-seventh of this amount would be $424, which would not be a large sum to write off revenue. It represents 3.13 per cent. of the first cost as against 33⅓ per cent. on the speculation system.

In the Shaw system the renewals would be:

Rails	$3 136 20
Removing and refixing ditto, say	440 00
Total	$3 576 20

One-seventh of this amount for yearly reserve fund would be $511 nearly, which represents 5.98 per cent. of the cost, with only longitudinal trenches of concrete, and 4.47 per cent. of the first cost with a complete concrete bed.

Street railways are in the main valuable and improving properties; easier to finance, quicker to yield a return, and more readily salable than larger railways. The speculative element is rapidly on the decrease, and promoters are coming to a sound cash basis as the best, and in the end most paying method, of organizing their enterprise. No prospectus which does not take renewals of track into account and show how they are to be met, ought to find acceptance with the investing public.

The question of renewals has another aspect. The general public is being continually tried in its proverbial patience, by needless interruptions of the traffic from the breaking up of the pavement in order to renew the track. The plain duty of municipal authorities is to see that the railway does not make its own interests unnecessarily conflict with those

of the community, but when once a cheap track is down, it has to be renewed constantly or the traffic must stop. The time for the municipality to act is when the concession is applied for. It would be perfectly fair for the authorities to stipulate for an inspector to be appointed by them at the expense of the company, who should see that the materials of construction were sound, and the work executed properly. There would then be less danger of old rails going down, as has been the case in some cities.

Rail Surfaces.

The question as to what is the best surface for a street railway track is not to be answered in a word. Numerous as are the designs which have been adopted in different countries, the chief considerations have been either on the part of the company to obtain a minimum resistance to traction, or immunity from the use of the track by other vehicles and a security from derailment; or else on the part of the city authorities to obtain a surface which will not obstruct the passage of any kind of vehicle across the track, or in some cases, and in direct conflict with the company's interests, to obtain a track which can and will be used by other vehicles, like the Deas rail already referred to.

The step-rail, whether as a single step in the form of side-bearing or double step in the form of center-bearing rails, continues to be the ruling type in America. The grooved rail was introduced into New York by M. Loubât in 1850, but its dimensions were so formidable that it was discarded, and the step-rail substituted—first in Philadelphia, and, until lately, throughout the United States, from the idea that the grooved rail was dangerous to wheel-tires, and because the railway companies preferred it.

In 1870 Mr. George Francis Train introduced the tramway to England with a step-rail. It gave such offense, that after losing his London concessions, he only saved those at Birkenhead by taking up the track and relaying with a grooved rail.

The groove in any form requires more cleaning than the step-rail, but as against this fact, it suffers less wear from passing vehicles. This is evident from the sight of heavy drays in their attempts to free themselves from the rail, scraping along its side for a considerable distance before they can mount it.

The wearing head of the center-bearing rail was made of a small radius to prevent wagons from riding on it, and this might also be done

with the grooved rail. As a matter of fact, when the streets are well paved, vehicles do not use the car track, but rather avoid it.

The latest cable roads in San Francisco have been made of 3-foot gauge, which not only gives less paving for the company to keep up, but also effectually keeps off vehicles. On this gauge, cars are perfectly stable when built of the same width as those of 4-foot 8½-inch gauge, even when traversing curves of 30 feet radius, if slowed down to 4 miles per hour.

The advantages of interchange of gauge is not of the same importance as on large railways. A line which does a good business does not want foreign cars to have running powers over it, neither is there much to be gained by bringing freight cars from steam railroads along the line at night, except for hauling coal to a power station.

Where streets are paved there is nearly always enough traffic to pay for a frequent service of cars. Grooves do not clog up much, and the busier the thoroughfare the more greasy is the mud which gets in them. Under those conditions it is fair to lay upon a company the small cost of groove cleansing.

On macadamized roads, even where the track itself is paved, the traffic is generally lighter and the roads are dustier. The dirt is always gritty, and produces much flange friction on the car wheels running in grooves.

In England tramway companies are compelled to use grooves on all roads, but it seems an unreasonable demand, when by laying the track on the side of the road a clear drive-way is afforded the public, and the inconvenience of crossing a step-rail almost entirely avoided.

The possible trouble from a frozen groove is one which it is difficult to estimate except from actual data, but in most cases, even in the coldest climates, it is liable to be exaggerated. If a dead level track froze hard after a fall of rain without any traffic upon it, it would require picking out with a hammer and cold chisel, but tracks have nearly always sufficient grade to pass the water off, and, as a matter of fact, one never does see a groove standing full of water. If only half-full, the car-wheel will run on its flange smoothly until it breaks the ice, and then run on the tread as usual.

General Conclusions.

First.—The wear upon the rail-head due to vehicular traffic combined

with that of the cars is very great as compared with steam railways, and different in its character. The rail is worn down by mere abrasion, long before either the shank or the lower flange has succumbed to fatigue or crystallization from the transverse stresses developed in them by the passing loads. Consequently economy calls loudly for a divorce between the head and lower member, or rather that they should remain together in a union which does not demand their simultaneous descent into the scrap heap.

Second.—The steel best adapted to resist attrition, has a larger percentage of carbon than the ordinary mild steel used in rail or girder construction.

Steel rails are now made with a higher percentage of carbon in America than in England. According to Mr. Sandberg, quoted by Mr. Tratman in his paper, they contain 0.50 to 0.60 per cent., special attention being devoted to hot pressing in the mills to avoid risk of fracture.

If, however, the rail-head were continuously supported and delivered from all transverse stresses, it might contain as great a percentage of carbon as would give it nearly the hardness of file steel, somewhere in the neighborhood of 1 per cent. A greater percentage of silicon might be permitted. Tungsten or chrome steel would be very suitable, and the specifications and tests for steel rails would be essentially different from those for steam railways.

Third.—The stringer, or longitudinal sleeper carrying the rail, should, if the ground underneath be solid, rest upon a concrete bed, and be so filled with the concrete as to obtain the supporting power of the concrete, and reduce the quantity of metal in the stringer to a minimum. Stringers made heavy enough to remain stable by their own inertia, or even including the weight of contained concrete, have but a small fraction of the stability obtained by using the tensile strength of the concrete itself in a properly bonded mass. Such systems endeavor to obtain, by the use of an expensive material, what they might do by a cheap one and fail to do it.

Fourth.—When intermittent supports are preferable, as upon the brackets of cable-yokes, or when the ground is weak and concrete would be liable to settlement, the stringer should be a girder of such a form that the material for resisting torsional and transverse stresses will be distributed in the most effectual manner—that is to say, material

should not be put into the web to obtain stability, but only to resist shearing. The upper and lower members of the girder, should be proportioned to the longitudinal stresses of tension and compression, according to the respective strengths of the material in each of those particulars. The stability or resistance to torsion should be inherent in the geometric figure of the girder, and not from an otherwise unnecessary thickness of the web. It should certainly not be dependent upon any agglomeration of bolting or riveting such as the high chairs, which have been well nick-named stilts, which may or may not be properly constructed, and upon which the same comment may be made as Dr. Johnson remarked upon the bear walking on its hind legs: "Very ingenious, but why should he do it?"

The elasticity of the track has already been touched upon, and it will suffice to remark, in summing up the matter, that the future of city transit will not probably produce much change in the conditions of roadbed. Motors will not probably be heavier than the storage battery car of to-day, and the speed will not exceed the limits prescribed by city authorities for security to the lives of foot-passengers ; consequently there will be no advance in the demand for elasticity in the city proper. There is likely, however, to be a great extension of electric lines into distant suburbs and adjacent towns, where the speed will vary from an 8-mile limit in the residential and business quarters, up to 20 miles upon the country roads. The type of construction would naturally require to be different, varying from a heavy imperishable and expensive roadbed, to the cheapest form of track which would properly carry the motor cars.

Fifth.—The sides of the stringer should be vertical to form a support to the paving blocks, and of sufficient depth to allow about an inch of sand between the bottom of the blocks and the concrete bed or metallic cross-ties, as the case may be.

Sixth.—No perishable material should be used in any part of the construction. As pointed out in Mr. Tratman's paper, the tendency of the steam railways is towards an all-metal construction, the first step being the use of bearing plates between rail and tie. The attention of the Department of Agriculture is being particularly drawn to the rapid denuding of the forests, and the attention of the railway companies is being drawn to the increased cost of lumber. It is probable that before long the question of steel rail supports for steam railways, either trans-

verse or longitudinal, will be answered by the introduction of an all-metal system, which will compete as to price, whilst it will vastly exceed in efficiency, the composite system of to-day.

Eagerness to obtain traveling facilities to assist rural development, still leads municipal authorities to permit the construction of cheap and perishable tracks, which in the course of a few years will have to be renewed, involving the removal of pavement and serious interruptions to the traffic and business of the streets.

Companies are open to the charge of having in many cases laid down a roadbed unequal to the business which they contemplated, without taking into account the strides that have been made by mechanical traction. They are now, however, adopting for their own sakes a much more durable type of construction. To sum up this point:

Municipalities should demand, intending investors should stipulate, and companies should for their own sakes specify, that not a particle of timber should enter into the construction of street railways under any kind of pavement, whether granite, asphalt or Nicholson. In macadamized roads it is also bad policy to use timber, but in graveled country roads, with light traffic, it is a question of that or nothing, and the track, placed on the side of road, can be renewed without much interruption of the traffic.

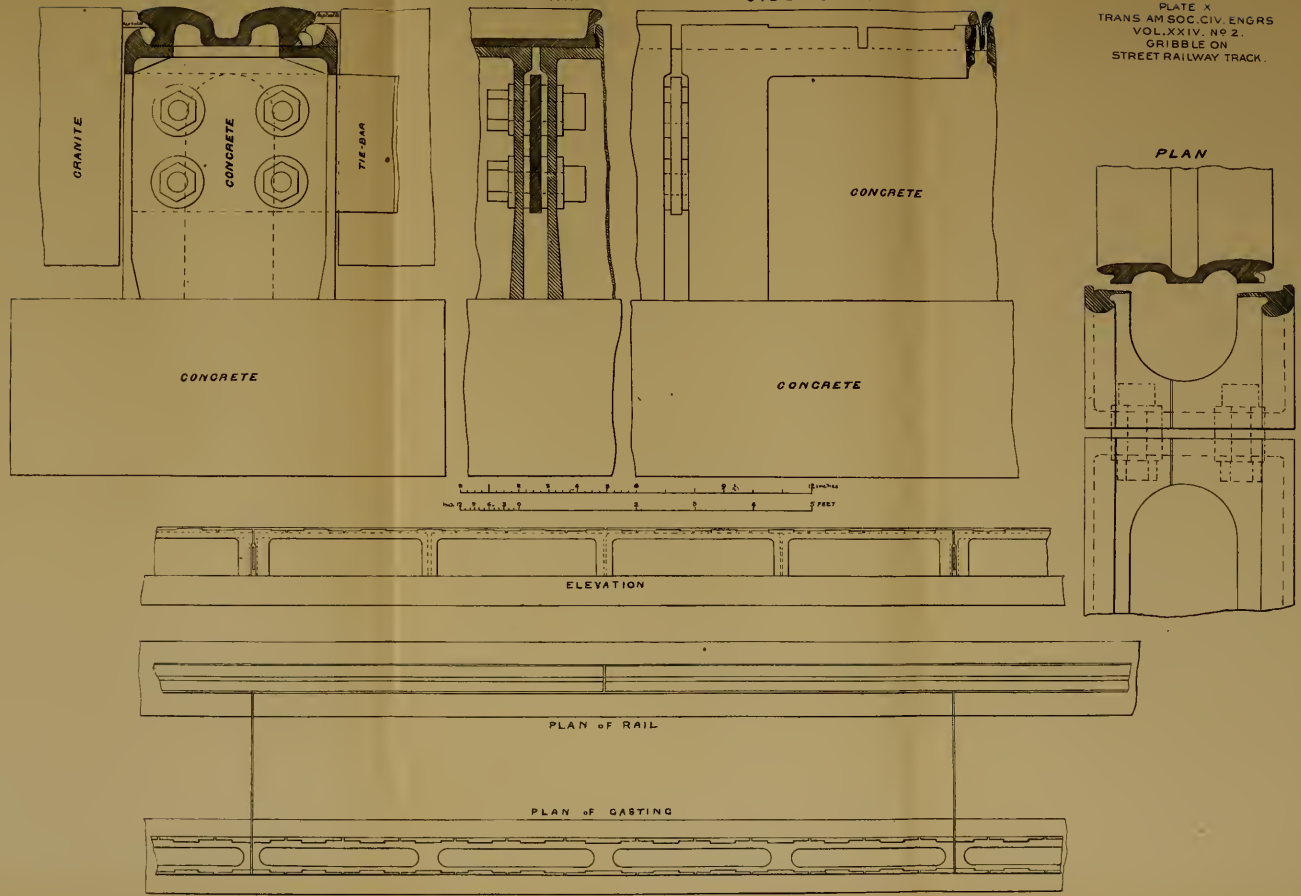
Seventh.—The attachment of the rail, which should be removable, should be accessible without disturbing the pavement. Several types of rail already described more or less fulfill this condition, and the points to aim at are as follows: To be able to replace the rail whilst the cars are running; to avoid piercing the rail or any kind of machining upon it; to apply the fastening in such a manner that the points of attachment will be external to the point of application of the load, and consequently not be subject to torsional stress.

Eighth.—A rail surface flush with the road outside and inside the track is only obtained by the grooved rail. It is, in paved streets, economical to the company, having regard to renewals, and both safe and convenient to the general public. On country roads, graveled or macadamized, a step-rail is greatly to be preferred by the company, and is permissible by the authorities. The track should, however, be laid on the side of the road.

Ninth.—The present gauge of 4 feet 8½ inches is unnecessary for stability of cars, and the 3-foot gauge, now being adopted in California,

The Gribble Box Girder Track System A with cast stringer.

PLATE X
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXIV. No 2.
GRIBBLE ON
STREET RAILWAY TRACK.

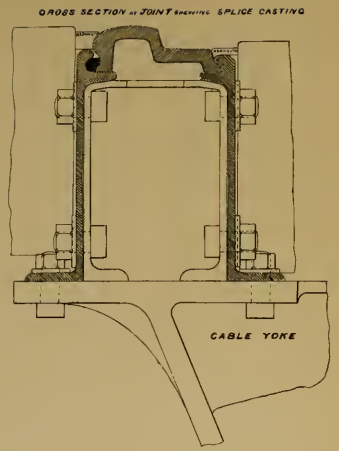


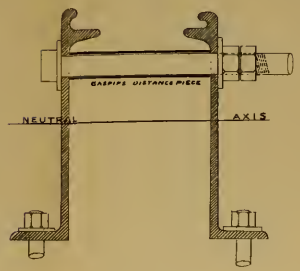
The Gribble Box Girder Track

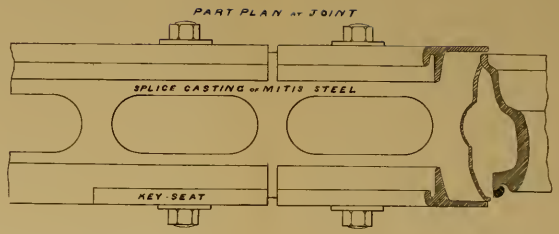
System B. with Rolled Beam Stringer

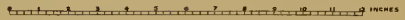
for Cable Roads or on Metal Crossties

Plate XI
Trans. Am. Soc. Civ. Engrs.
Vol. XXIV. No. 2.
Gribble on
Street Railway Track.



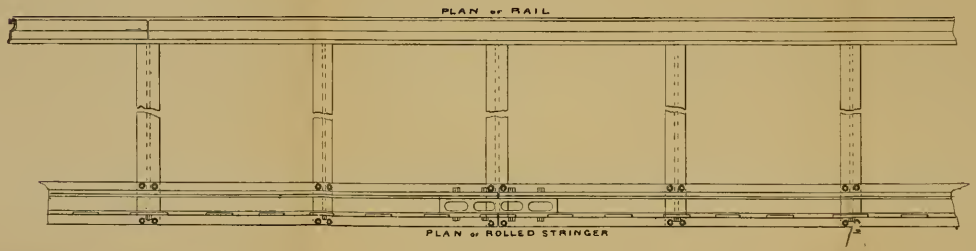






Elevation

Plan of Rail



Plan of Rolled Stringer

Weight per Yard.

Rail,	22 Lbs.
Girder,	56 "
Total,	78 "

Moment of Inertia (ex rail) 2060 c. in.

The Cribble Box Girder Track

System C. Attachment without wedges.

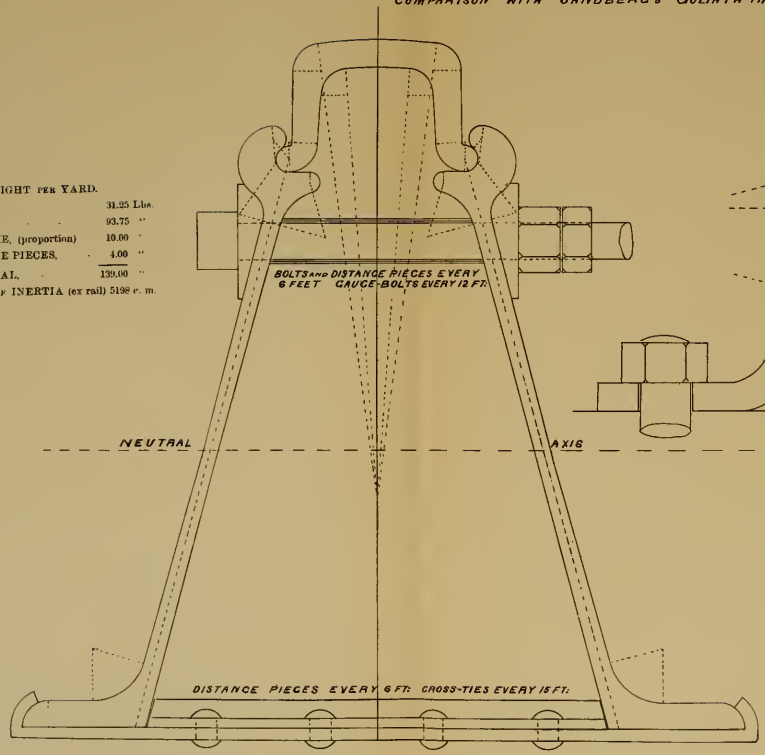
Comparison with Sandberg's Goliath Rail

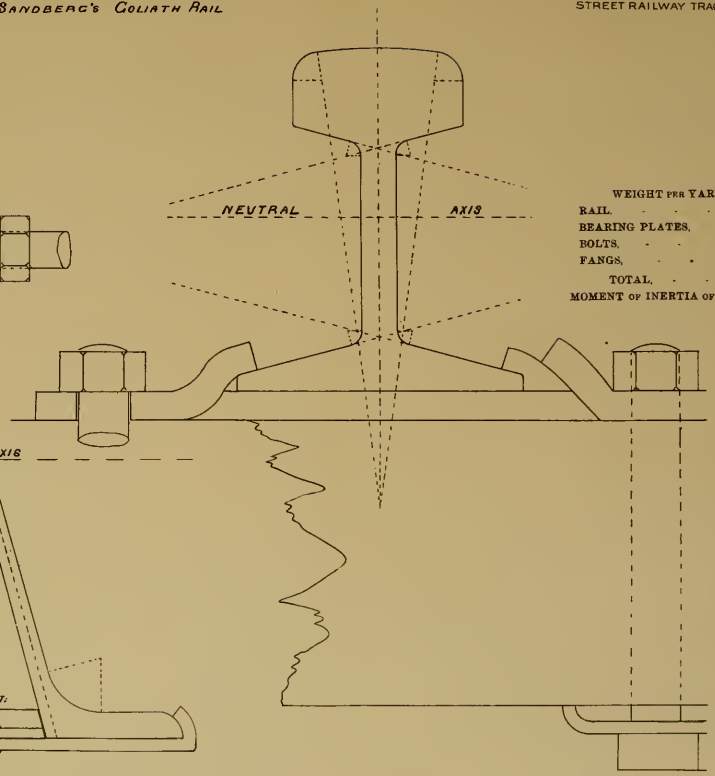
PLATE XII
TRANS AM. SOC. CIV. ENGRS
VOL. XXIV. Nº 2.
GRIBBLE ON
STREET RAILWAY TRACK.

WEIGHT PER YARD.

RAIL,	31.25 Lbs.
GIRDER,	93.75 "
CROSS TIE, (proportion)	10.00 "
DISTANCE PIECES,	4.00 "
TOTAL,	139.00 "

MOMENT OF INERTIA (ex rail) 5198 c. m.





WEIGHT PER YARD.

RAIL,	100.00 Lbs.
BEARING PLATES,	19.20 "
BOLTS,	15.10 "
FANGS,	4.21 "
TOTAL,	138.51 "

MOMENT OF INERTIA OF RAIL 1932 c. m.

SCALE

0 1 2 3 4 5 6 INCHES

is preferable, not only for economy in paving, but also for preventing the use of the track by foreign vehicles.

Box Girder Track Suggested by the Author.

Plates X, XI and XII, are explanatory of the way in which the author has attempted to embody the views above expressed. The use of metallic keys is not a novelty, but the arrangement of them in a continuous series has been adopted in order to preclude all liability to working loose, and to provide a strength greatly in excess of any stress that can be estimated upon them. Considering the lugs under three forms of stress, vertical, horizontal or intermediate, whether in direct shearing or transverse strain, it would require a force of over 100 tons to remove the rail from one 12-foot box.

The protection of the lugs by a covering of sand and asphalt was suggested by the experience at Honolulu with the grooved rail shown on Fig. 4. The space is in no case as much as an inch, so that nothing but a very light buggy wheel could come on it. In macadamized or graveled roads a single longitudinal row of granite paving blocks should be laid on each side. The method of construction would be to lay the longitudinal bed of bottom concrete first, and then align one casting from the surveyor's center line. On the cast stringer there is a nick marking the gauge line. The casting, 12 feet long, can be lifted easily by two men, and can be aligned and leveled in a few minutes, so that the bottom bed will not have begun to set during the process; side boards are then placed to retain the concrete filling, which is introduced from the opening at the top by means of funnels, and packed close up to the sides by bent irons. The concrete is then allowed to set, the side boards removed, and the upper surface rendered in cement mortar flush with the metal. The second line of stringers is aligned from the first by gauge-bars. Tie-bars are shown on the drawing. They will be only required for curves, and it is doubtful if they will be wanted there. The keys will be driven or removed by a bent steel die, terminating in a shank fitting into a striking piece separate from it. The keys themselves will be of lead, or mitis casting, or possibly oak. For the lug holding the rail-joint a key of lead would be preferable, because the ends of the rails, not being perfectly similar, would obstruct its passage less. The lugs will have a slight taper, and when the key is driven it will be slightly upset, or clinched by striking it at both ends simultaneously. The lug over the joint is made

longer than the others. There will be much more bearing surface on the keys than on the key of Mr. Sandberg's Goliath rail, illustrated in Mr. Tratman's paper, although subjected to much less shock.

The rail will be inserted or removed sideways. Frogs and switches will also be reduced to nothing more than a wearing surface removable in similar manner, resting whether in system *A* or *B* upon a casting. If in system *A*, the casting will be filled with concrete, but if in system *B*, it will be furnished with bottom flanges and bolted to metallic cross-ties.

Comparisons of cost are difficult to make, when the cost of single track under present systems varies from $6 000 to $30 000 per mile according to circumstances. Such statements are, moreover, generally received with much reservation as to possible exaggeration in favor of the promoters' own ideas. It is preferable to compare quantities of material, and for the sake of illustration, a girder-rail system with a 78-pound rail mounted on a steel chair attached to a chestnut cross-tie, will be compared with proposed systems *A* and *B*. The prices adopted by the author for his own estimates give with steel at 2 cents per pound, cast-iron at 2 cents per pound, and concrete at 25 cents per cubic foot, a slight advantage to the girder-rail; whilst with prices at 2 cents for steel, 1¾ cents for cast-iron, and 20 cents for concrete, the advantage would be somewhat the other way. A 12-foot casting weighs from 120 pounds upwards = 30 pounds per yard. The rail from 20 pounds per yard. The weight of metal is, therefore, about the same as in the girder-rail with chairs.

The renewal would be about one-fifteenth part of that of the girder system when laid with timber cross-ties, allowing a life of seven years to the wearing head of the girder-rail and then the renewal of all things. In the author's system there might be a life of fourteen years to the wearing head, due to increased hardness of the material, without taking into account the reversing of the rail, which would also have its value. In the end of that time there would only be a weight of about 25 pounds per yard of renewal, the stringer remaining as permanent as the foundations of a house or the bed-plate of an engine.

System *B*, with Rolled Stringer.

In this case, see Plate II, the material has been arranged to combine vertical sides, a broad base, and a symmetrical arrangement of tension

and compression members. Following up the comparison of different rails previously given, the system *B* stringer would have a moment of inertia of 2 060 c. m., for a 78-pound section, and the cost of renewal would be only that of the wearing head.

Joints.

In the system with cast stringers and concrete, the expansion upon one 12-foot casting due to 100 degrees Fahr. would be 0.089 inch; the expansion of the concrete, assuming it at one part in 100 000 per degree Fahr., would be 0.144 inch. The difference of 0.055 inch would not exceed the elastic limit of good cast-iron if produced as an extension upon it by the concrete, but a cushion of sand will be left at the end of the castings to take up this expansion, and washers of split steel used between the two castings to permit the metal to expand.

At every 24 feet a half-inch board will be placed so as to form a division in the lower concrete, and withdrawn when the latter has set.

In the systems with rolled stringers, the joint is formed by a saddle-casting forming an internal support to both the upper surfaces and sides of the beams, its depth permitting the use of bolts with great leverage of resistance to deflection.

The casting will be furnished with openings for bolting, and the whole stringer will be filled with ballast before the rail is laid on.

System *C*.

Though scarcely within the range of the subject of this paper, a brief comparison will be made between the box-girder principle applied to the Goliath 100-pound rail of Mr. Sandberg. The principle holds good for lighter rails down to a 50-pound section, and as street railways running into suburbs often use flanged tee-rails, it may be as well to complete the description of the box-girder system with its application to any kind of heavier railway.

The moment of inertia of the Sandberg rail is 1 932 centimeters. Comparing it first of all with the 78-pound street railway girder-rail, illustrated, Fig. 16, whose moment of inertia is 1 603 centimeters, it will be noticed: 1st, That the shank is much wider in the Goliath, and the flanges deeper at the throat. In the street rail the material is massed at the extremities, so that it has the same depth as the Goliath and a wider bottom flange. Consequently, although it has

only 78 per cent. of the area, it has 83 per cent. of the moment of inertia. Recollecting that moments of inertia of similar figures vary as the squares of their respective areas, the girder-rail shows a very much stiffer figure than the Goliath. This is no reflection upon the Goliath, because the two rails are in very different lines of business. The Goliath needs an elephantine trunk to stand the torsional stresses of heavy locomotives. Both are well designed for their duties.

Next, comparing the Goliath with the box-girder, system *C*, we find very remarkable results. In the latter, in order to give it a sufficient base for supporting the rail as a longitudinal stringer with only an occasional cross-tie, the equivalent weight per yard of rail has been substituted for the Sandberg bearing plates, fangs and bolts.

	Pounds. Per yard forward.
Wearing head	31.25
Box-girder stringer	93.75
Cross-tie, every 15 feet	10.00
Distance pieces and gauge bars	4.00
Total steel per yard run	139.00

The stability of figure is 1, as against 0.833 in the Goliath. That is to say the box-girder has 20 per cent. more stability, although it has twice the depth. The moment of inertia is 5 198 centimeters, or 169 per cent. more than the Goliath.

Placed side by side on bearings 10 meters apart the deflection of the Goliath under a uniform load of 5 tonnes* per meter would be 4.95 centimeters. The deflection of the box-girder would be 1.84 centimeters.

The strength is increased by 62.2 per cent. The Goliath rail would be safe under a load of 5 tonnes per meter on a span of 3.10 meters, *i. e.*, with 15.5 tonnes upon it. The box-girder would be safe on a span of 4.00 meters with a load of 5 tonnes per meter, *i. e.*, with 20 tonnes upon it, uniformly distributed; ordinary 12-foot culverts would be spanned by the box-girder without any assistance, and by rolling the beams 12 inches deep, making the total depth 15 inches, small bridges of 15 to 18 feet could be spanned by it.

The rail is designed to be under compression alone, and is in effect a pivoted arch, having an articulated line of thrust which passes

* French tonnes of 1 000 kilogrammes.

directly down the center of the rolled beams. These are very thin at the center, being supported from buckling by the filling within and the ballast without. If used to span culverts they would either be rolled thicker or have stiffeners. They are held together by a light distance piece every 6 feet, and a steel cross-tie every 15 feet, the latter not for bearing surface but to keep the beams out of winding. They are held at top and hold the rail by a $\frac{5}{8}$-inch bolt every 6 feet, which at every alternate point, that is at every 12 feet, terminate in right and left-handed screws to receive a gauge-bar with turnbuckle.

A freedom is allowed in the lower fastening to admit a movement in the jaws of $\frac{3}{16}$ of an inch for inserting the rail, and lock-nuts are provided for keeping it tight.

Before inserting the rail the box will be filled with loam, sand or peat, and the rail also filled bottom up, so that when in place the girder in settling down to its bearing on the ballast will leave a cushion for the ballast to work up into, and so diminish vibration; in addition to this some strips of tarred felt will be placed between the rail and the jaws. It is submitted that by this method 80 per cent. of the track would be constituted an asset of the company, subject to no greater depreciation than the bridges or station buildings; furthermore, that the rail could be safely composed of a steel which would outlast two of the present mild type; last, but not least, that there would be no danger of accident from broken rails, and this at the same initial cost.

The Crossing of Larger Railways by Street Railways.

The state of the law in America regarding this matter, appears to be that the railway company having the priority of right, is not only entitled to compensation in respect of any interference with its adjacent roadbed; to payment for extra supervision of the crossing as a precaution against accidents, but also to entire immunity from interference with its rail-surface by the tramway.

The mode of procedure is generally as follows:

The street railway gives notice of its intention to cross the larger railway, and is received with diplomatic reserve.

The street railway then proceeds to lay its track up to and between the rails of its great-cousin, and is received with a club.

Litigation follows, terms are agreed upon, and finally the street car is permitted, for a consideration, to come up to, jump over the heavier rail, and wend its way in peace.

The temper of the steel car-springs and that of the passengers inside is equally tried by the process, but with characteristic patience, and thinking probably that it is to save accidents, the latter make no objection.

If the cutting of the rails of the steam railway were necessarily attended with danger, it would be imperative that the street car should mount the other rail, whatever the inconvenience; but since, in a very great number of cases steam railway cars cross one another's lines on the level by cutting the track, that is to say, by putting in square frogs, this argument has no force. There must be considerably less chance of derailment of a car on such a crossing than when jumping over the larger rail upon its flange.

The priority of position on the part of the larger railway, is the foundation of its claim. It has been granted a right of way by the State, and demands to keep it without any interference. But there is a broader view of the question, which is coming more and more to the front all over this continent. The proper place for high-speed trains is not upon the surface of the highways. A steam dummy going at 10 miles an hour is bad enough, but the passage of a rushing train across crowded thoroughfares, will soon be generally looked upon as a reckless disregard of human life, unworthy of a paternal government.

The street car in whatever manner operated, but regulated by local supervision, is the right thing in the right place, but the locomotive, whatever its right of way, is destined to be put somewhere out of the way of pedestrians. As long, then, as it remains where it is by public sufferance, it may be fairly called upon to diminish its speed and cross the street car line by a similar crossing to that which would be put in for crossing another steam railway, and there seems no reason why a general statute should not be framed, which would adjust compensations so as to avoid litigation in all ordinary cases. Being a matter of public safety and convenience, it would be as appropriately treated by legislation, even down to the form which the crossing should take, as the matter of signals, platforms, or other points of railway construction which are subject to Government rules and inspection.

Curves.

The use of parabolic or transition curves, is becoming imperative upon street railways. The radii cannot be increased, but the speed is

constantly being accelerated by the introduction of mechanical traction. The company protects its cars from derailment upon sharp curves by means of guard rails, but cannot prevent its passengers from the unpleasant swing and jolt when the cars turn a corner, nor can it avoid the wear and tear to the car wheels and axles from the sudden cross strain.

It is noticed by locomotive superintendents, that the wear of tires on single-line railways with frequent crossing stations, is more on one side than the other, although the right and left-handed curvatures may be equal. This arises from the fact that trains enter crossing stations quicker than they leave them, and wear the running gear on the side on which they strike the facing points.

Formerly switches of street railways were operated by the driver, and the car was almost at a standstill. Very sharp switches were made to economize length, and the horses helped the car round. Now, with higher speeds and switches worked either automatically or by a switchman, it is advisable to have them nearly as long as those on steam railways, so that the car may traverse them with undiminished speed.

The parabola is the curve which gives a uniformly accelerated resistance to rotation, and is sometimes put in by ordinates from tables, but it is not a convenient figure for calculation or for combination with circular curves. Mr. Searles in his "Railroad Spiral," uses a combination of circular curves, which is in alignment sensibly a cubic parabola, but has the advantage of being readily calculated from the properties of the circle, and still more readily laid off upon the ground. He uses a basic angle of ten minutes, by which he uniformly increases the curvature. The chord may be anything, but the increment of curvature and total curvature from commencement, are the same for any point in the spiral. Thus, whether with a chord of 2 feet or 100 feet, the total curvature at the first point is ten, at the second point twenty minutes, and so on. In the author's book on "Preliminary Survey," recently published, a series of tables has been arranged for decimal degrees, which simplify the calculation, and the basic angle is 0.2 degrees; that is to say, twelve minutes. A book of trigonometrical functions for decimal notation, by Dr. Bremiker, of Berlin, may be procured at trifling cost from Messrs. Keuffel & Esser, of New York City. It is the original notation of Briggs, in 1633, followed by Oughtred, in the hopes of getting rid of the senseless sexagesimal subdivision which has, how-

ever, survived in triumph. Instruments can be adapted to the decimal subdivision by merely altering the vernier. The spiral may be applied in complete form to take the place of a circular arc or else only as a transition into a circular arc. Even upon the sharpest curves the combination of a pair of spirals with a circular connecting or "crowning" curve, occupies very nearly the same ground as a plain curve, the difference consists in, firstly, an earlier commencement of the curvature; secondly, a slightly sharpened curvature at the crown; thirdly, a somewhat greater clearance of the crown from the sidewalk.

Table A gives the general elements of the decimal spiral. Table B gives the co-ordinates of a spiral, with a chord of two units. When taken as feet it becomes a very suitable spiral for street railways. Table C gives the co-ordinate of a parallel spiral 4.75 feet beyond B. Taken at 4 feet 9 inches, it is suitable for the outside rail on standard gauge.

The following are the most simple problems for which formulas are required:

Problem I.

Given the co-ordinates x, y of a point in a spiral, the total curvature $\triangle$ or half-curvature Θ, and the radius of a desired crowning curve; to find the point of spiral or distance, $I\,S$, from the point of intersection of the main tangents to the point of commencement of the spiral, also the apex distance $A\,I$, or distance from intersection of main tangents to crown of curve.

$$I\,S = y + \tan.\ \Theta\ (R \cos.\ s + x) - R \sin.\ s.$$

$$A\,I = \frac{R \cos.\ s + x}{\cos.\ \Theta} - R.$$

Example.—It is desired to put in a spiral having a total curvature of 90 degrees, the spiral proper being carried up to point 13, and from thence a crowning or connecting curve of 40.93 feet radius:

$I\,S = 25.73 + \tan.$ 45 degrees $(40.93 \times \cos.$ 18.2 degrees $+ 2.84)$ —, 40.93 sin. 18.2 degrees $= 54.67$.

$$A\,I = \frac{40.93 \cos.\ 18.2 \text{ degrees} + 2.84}{\cos.\ 45 \text{ degrees.}} - 40.93 = 18.07.$$

TABLE A.

General Elements of the Decimal Spiral.

No. of Point. n.	Curvature in one chord. $n\,c$. Degrees.	Total Curvature up to n. s. Degrees.	Total Curvature up to mid-chord or deflection of short chord from main tangent. k. Degrees.	Tangential angle or angle between long chord and main tangent. i. Degrees.
1	0.2	0.2	0.1	0.1
2	0.4	0.6	0.4	0.25
3	0.6	1.2	0.9	0.47
4	0.8	2.0	1.6	0.75
5	1.0	3.0	2.5	1.10
6	1.2	4.2	3.6	1.52
7	1.4	5.6	4.9	2.00
8	1.6	7.2	6.4	2.55
9	1.8	9.0	8.1	3.17
10	2.0	11.0	10.0	3.85
11	2.2	13.2	12.1	4.60
12	2.4	15.6	14.4	5.41
13	2.6	18.2	16.9	6.30
14	2.8	21.0	19.6	7.24
15	3.0	24.0	22.5	8.26
16	3.2	27.2	25.6	9.33
17	3.4	30.6	28.9	10.48
18	3.6	34.2	32.4	11.68
19	3.8	38.0	36.1	12.95
20	4.0	42.0	40.0	14.29
21	4.2	46.2	44.1	15.69

Problem 2.

Given the apex distance, total curvature and co-ordinates x, y of a point in the spiral to find the radius of crowning curve, and commencement of spiral.

Here it is necessary to find two auxiliary angles λ and μ from the given ones, Θ and S:

$\lambda = 90$ degrees $- \frac{1}{2}(\Theta + s)$ and $\mu = 90$ degrees $- \frac{1}{2}(\Theta - s)$ and as a check; $\lambda + \mu + \Theta = 180$ degrees.

$$R = \frac{A\,I \cos.\ \Theta - x.}{2 \cos.\ \lambda \cos.\ \mu.}$$

$$I\,S = y + \tan.\ \lambda\,[(A\,I \cos.\ \Theta) - x] + A\,I \sin.\ \Theta.$$

Example.—Total curvature, 90 degrees. Apex distance, 16.40 feet. Spiral, 22 feet long, *i. e.*, to end at point 11:

$\lambda = 60.9$ degrees ; $\mu = 74.1$ degrees. $\Theta = 45$ degrees. $x = 1.759$ feet $y = 21.878$.

$$R = \frac{16.40 \times \cos.\ 45 \text{ degrees} - 1.76}{2 \cos.\ 60.9 \text{ degrees} \times \cos.\ 74.1 \text{ degrees.}} = 36.93 \text{ feet.}$$

TABLE B.

Elements of Street Railway Spiral with Chords of Two Units. Plate IV.

n.	Radius. r.	Co-ordinate at right angles to tangent. x.	Co-ordinate in line of tangent. y.	Length of curve. l.
1	572.96	0.003	2.000	2
2	286.48	0.017	4.000	4
3	190.99	0.049	6.000	6
4	143.24	0 105	8.000	8
5	114.59	0.192	9.999	10
6	95.49	0.318	11.993	12
7	81.85	0.488	13.986	14
8	71.62	0.711	15.973	16
9	63.66	0.993	17.953	18
10	57.30	1.340	19.923	20
11	52.09	1.759	21.878	22
12	47.75	2.257	23.816	24
13	44.08	2.838	25.729	26
14	40.93	3.509	27.613	28
15	38.20	4.274	29.461	30
16	35.81	5.139	31.265	32
17	33.71	6.105	33.016	34
18	31.84	7.177	34.704	36
19	30.16	8.355	36.320	38
20	28.65	9.641	37.855	40
21	27.29	11.033	39.288	42

TABLE C.

Elements of Parallel Spiral at a Distance of 4.75 Units from that in Table B.—Plate IV.

n.	Radius r.	x.	y.	l.
1	577.71	0.003	2.017	2.017
2	291.23	0.017	4.050	4.050
3	195.74	0.050	6.100	6.100
4	147.99	0.107	8.165	8.166
5	119.34	0.198	10.246	10 249
6	100 24	0.330	12.341	12.348
7	86.60	0.511	14.449	14.464
8	76.37	0.749	16.568	16.597
9	68.41	1.051	18.696	18.746
10	62.05	1.427	20.829	20.912
11	56.84	1.885	22.963	23.094
12	52.50	2.432	25.093	25.293
13	48.83	3.076	27.213	27.509
14	45.68	3.825	29.316	29.741
15	42.95	4.685	31.393	31.990
16	40.56	5.664	33.436	34.255
17	38.46	6.767	35.434	36.537
18	36.59	7.996	37.375	38.836
19	34.91	9.362	39.245	41.151
20	33.40	10.861	41.031	43.482
21	32.04	12.495	42.717	45.830

PLATE XIII
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GRIBBLE ON
STREET RAILWAY TRACK

FIG. 4.

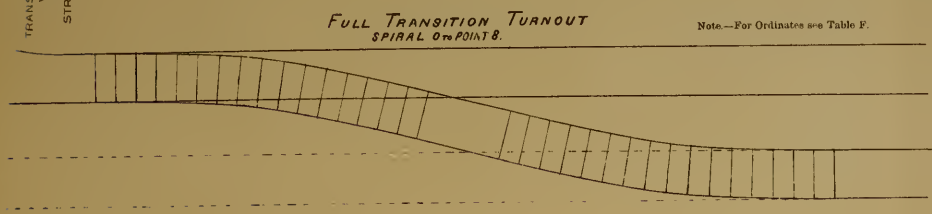
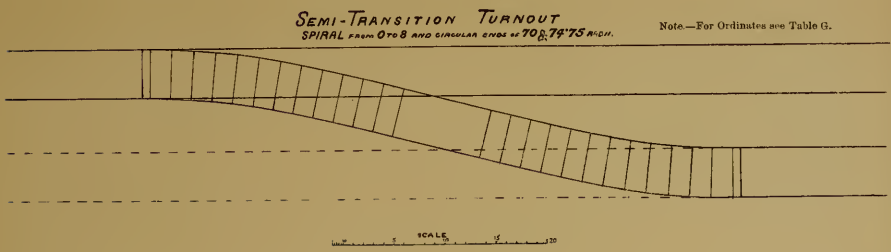


FIG. 3.



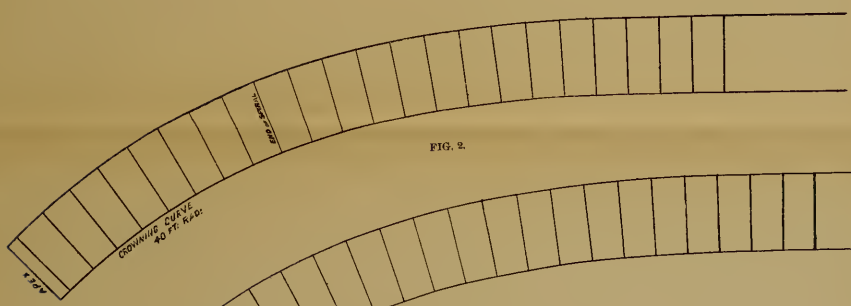


FIG. 2.

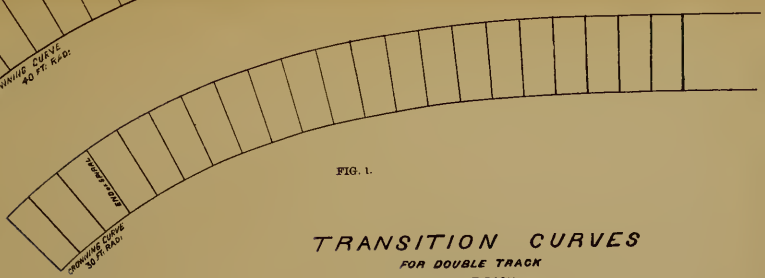


FIG. 1.

TRANSITION CURVES
FOR DOUBLE TRACK
30 AND 40 FEET RADII
TOTAL CURVATURE 90 DEGREES
SCALE

Note.—For Ordinates see Tables B. C. D. E.

$IS = 21.88 + \tan. 60.9$ deg.: $\times$ [(16.40 cos. 45 deg.)—1.76]—16.40 sin. 45 deg. = 51.16 feet.

The intermediate way between the tracks is made 5.25 feet, but in order to make a harmonious transition from the inner spiral to a 30-foot crowning curve, the spiral has been continued to point 18, which makes the intermediate way wider at the crown. If it were necessary to keep the intermediate way the same width, it would be necessary to stop the spiral at point 12 where the radius of curvature is 47.75 feet, and there would therefore be a less perfect transition, but still practically imperceptible to the traveler.

Double track transition curves for a square street corner are shown on Figs. 1, 2, Plate IV, and the ordinates given on Tables D and E.

TABLE D.

Co-ordinates of Crowning Curves for Double Track Quadrants.—Spiral to End at Point 14.—Plate IV, Fig. 2.

Outside Track.

Co-ordinates of Outer Rail. Radius 44.75.			Co-ordinates of Inner Rail. Radius 40.		
No.	x.	y.	No.	x.	y.
14	3.825	29.316	14	3.509	27.613
15	4.675	31.387	15	4.269	29.465
16	5.628	33.413	16	5.120	31.277
17	6.679	35.391	17	6.059	33.045
18	7.826	37.314	18	7.084	34.765
19	9.067	39.177	19	8.192	36.431
20	10.398	40.977	20	9.381	38.040
21	11.815	42.709	21	10.647	39.589
22	13.317	44.368	22	11.988	41.073
Apex.	13.907	44.971	Apex.	12.516	41.612

TABLE E.

Spiral to End at Point 18—See Fig 1, Plate IV.

Inside Track.

Co-ordinates of Outer Rail. Radius 34.75.			Co-ordinates of Inner Rail. Radius 30.0.		
No.	x.	y.	No.	x.	y.
18	7.996	37.375	18	7.177	34.704
19	9.374	39.243	19	8.366	36 317
20	10.872	41.017	20	9.661	39.849
Apex.	12.193	42.413	Apex.	10.801	39.055

Turnouts.

The application of the spiral in Tables B and C to a turnout, will produce a switch nearly as easy as that of a steam railroad; but by reason of the accelerating curvature, a much less frog distance.

The diagram, Plate IV, Fig. 4, is composed entirely of spirals, but if the length of the turnout were longer than the authorities allowed, the diagram, Plate IV, Fig. 3, shows a semi-transition turnout which is composed of a circular curve for the switch, but forming a transition reverse-curve at the frog. The short piece of tangent at the frog relieves the car from the unpleasant swaying motion experienced when passing over an ordinary reverse curve. The ordinates are given on Tables F and G.

The author desires to state in conclusion that although he has endeavored to verify the accuracy of his calculations, it has been not without some apprehension that he has presented a novel form of construction to the criticism of an audience such as this.

He hopes, however, whether his views are shared by his hearers or not, that the historical *résumé*, and criticisms of modern types of construction, may furnish at least some suggestive thoughts to members of this Society.

TABLE F.

Co-ordinates of Full Transition Turnout.—Fig. 4, Plate IV.

Gauge, 4.75; Intermediate way, 5.45; Radii at crown, 71.62 and 76.37.

Left-hand Rail.

No.	x.	y.	No.	x.	y.
1	0.003	2.017	18 (P. S.)	6.205	40.829
2	0.017	4.050	19	6.699	42.767
3	0.050	6.100	20	7.183	44.708
4	0.107	8.165	21	7.649	46.653
5	0.198	10.246	22	8.093	48.603
6	0.330	12.341	23	8.505	50.560
7	0.511	14.449	24	8.879	52.524
8	0.749	16.568	25	9.210	54.497
9	1.045	18.679	26	9.489	56.477
10	1.395	20.767	27	9.712	58.464
11	1.788	22.829	28	9.882	60.457
12	2.217	24 868	29	10.008	62.453
13	2.676	26.881	30	10.095	64.451
14	3.153	28.875	31	10.151	66.450
15	3.645	30.848	32	10.183	68.450
16 (P. T.)	4.144	32.802	33	10.197	70.450
17 (Frog).	4.750	35.162	34	10.200	72.450

TABLE F.—(*Continued.*)

Right-hand Rail.

No.	x.	y.	No.	x.	y.
1	0.003	2.000	18 (P. S.)	6.056	39.648
2	0.017	4.000	19	6.555	41.602
3	0.049	6.000	20	7.047	43.575
4	0.105	7.999	21	7.524	45.569
5	0 192	9.997	22	7.983	47.582
6	0.318	11.993	23	8.412	49.621
7	0.488	13.986	24	8.805	51.683
8	0.711	15 973	25	9.155	53.771
9	0.990	17.953	26	9.451	55.882
10	1.321	19.926	27	9.689	58.001
11	1.695	21.890	28	9.870	60.109
12	2.107	23.847	29	10.002	62.204
13	2.551	25.797	30	10.093	64.285
14	3.017	27.742	31	10.150	66.350
15	3.501	29.683	32	10.183	68.400
16 (P. T.)	3.995	31.621	33	10.197	70.433
			34	10.200	72.450

TABLE G.

Co-ordinates of Semi-Transition Turnout.—Fig. 3, Plate IV.

Gauge, 4.75; Intermediate way, 5.25; Radii at commencement and ends Inner rail, 70.00; Outer, 74.75.

Left-hand Rail.

No.	x.	y.	No.	x.	y.
1	0.005	0.848	15 (P. S.)	6.165	34.097
2	0.060	2.986	16	6.659	36.035
3	0.175	5.118	17	7.143	37.976
4	0.351	7.248	18	7.609	39.921
5	0.590	9.368	19	8.053	41.871
6	0.883	11.462	20	8.466	43.828
7	1.234	13.552	21	8.838	45.792
8	1.624	15.614	22	9.170	47.767
9	2.054	17.652	23	9.448	49.746
10	2.513	19.667	24	9.671	51.732
11	2.990	21.660	25	9.836	53.726
12	3.482	23.633	26	9.944	55.723
13 (P. T.).	3.984	25.603	27	9.995	57.725
14 (Frog).	4.750	28.587	End.	10.000	58.518

TABLE G.—(*Continued.*)

Right-hand Rail.

No.	x.	y.	No.	x.	y.
1	0.005	0.794	16	6.518	34.886
2	0.056	2.796	17	7.010	36.859
3	0.164	4.793	18	7.487	38.852
4	0.329	6.787	19	7.946	40.867
5	0.562	8.773	20	8.376	42.905
6	0.830	10.752	21	8.766	44.967
7	1.162	12.727	22	9.117	47.057
8	1.534	14.691	23	9.410	49.151
9	1.947	16.648	24	9.649	51.271
10	2.391	18.598	25	9.825	53.401
11	2.857	20.543	26	9.946	55.533
12	3.341	22.484	27	9.995	57.671
13 (P. T.)	3.835	24.422	End.	10.000	58.519
15 (P. S.)	6.016	32.916			

DISCUSSION.

Edward P. North, M. Am. Soc. C. E.—Before the technical part of this paper is taken up I want to call attention to a clause on the first page, where Mr. Gribble says: "But if her municipalities have erred on the side of leniency to corporations at their inception for the sake of progress, they have known also how to make up for it afterwards in rates and taxes." As this paper is read before this Society, and will have some weight outside of this country for that reason, I think Mr. Gribble should modify that statement. It has been utterly impossible so far, or until within a very recent time, to collect even the license fees for cars on our street railroads. I think that they are perfectly irresponsible to the city. They have in one instance altered the grade of the street so that it was necessary to remodel the street, and in a good many other cases they have gone on in this city entirely without regard to the ordinances of the Department of Public Works. I do not think they have ever paid any taxes, but I will not be certain of that. I think Mr. Gribble will alter that sentence if he investigates the matter.

E. E. Russell Tratman, Jun. Am. Soc. C. E.—Mr. Gribble having referred to my paper, which was published in the Transactions, March, 1890, I am pleased to offer the following remarks in discussion of his paper. Mr. Gribble speaks to the point when he says that municipal authorities should stipulate that the materials and work in the construction of street railways should be under the supervision of an inspector to be appointed by them. I would go further, however, and say that the authorities should in the first place require the type of track and general form of construction proposed, to be approved by an engineer, and then that the materials and work should be under the supervision of an engineer and a competent inspector. Politics should not be allowed to enter into consideration in such work. The necessity of a good foundation for the track is universally admitted: the concrete base, 9 inches thick, of one English line is composed of one part of Portland cement, two of sand, and five of broken stone or gravel. As an example of the class of street-railway track very generally adopted in the smaller cities and towns (and not unfrequently found in the larger cities) of this country, I may instance a line in an Ohio town, the specifications for which were sent me in 1889. The rails were flat, of side-bearing section, 3¾ inches wide, and weighing 27 pounds per yard; they were spiked to stringers 15 feet long, 6 inches wide, 4 inches deep, which were placed upon cross-ties 5 feet 6 inches long, 6 inches wide, and 6 inches deep. The ties were spaced 5 feet apart in the clear, and the stringers were secured to them by cup-headed spikes 8 inches long and ⅝ inch square. At the rail joints there were bearing-plates 3¼ inches wide, 12 inches long, ⅜ inch thick. There was one curve of 40 feet radius upon which channel rails were to be used.

Much information in regard to track will be found in the reports of 1884 and 1885 of the American Street Railway Association; and I may

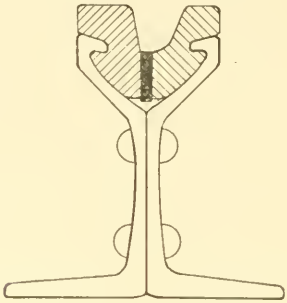


Fig. 20.

Improved Meakin Compound Rail.

mention (as Mr. Gribble recommends a gauge of 3 feet) that the report for 1884 advocated a gauge of from 4 feet 8 inches to 5 feet 2 inches. I quite agree with the author as to the desirability of having a removable wearing surface, and in this connection present a sketch (Fig. 20) of an improved form of the Meakin rail illustrated by Mr. Gribble. The rail proper is in two pieces, which are dropped into place in the head of the iron longitudinal, and are secured by a slightly taper bar which forms the bottom of the groove; this form of rail is said to have been tried in

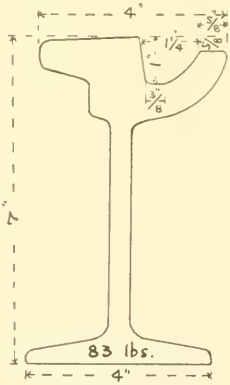


Fig. 21.

Grooved Girder Rail; New York, N. Y.

England on the Southeastern Railway and on the South London Tramways. A very good track for country roads can be made with ordinary tee-rails, and for particulars of such track I would refer to an article of mine on "Country Tramways," published in *Engineering News*, New York,

April 6th, 1886. With a good type and construction of track, there should be a good street foundation, and paving from curb to curb, as in England and other European countries, where grooved rails are used. In regard to several remarks which have been made as to the street paving, I would say that it would be poor policy to adopt a good system of track for a city street, without adopting a good pavement. Without such pavement, ruts and an irregular surface will be formed, and the advantages of the improved track be thus lost to a considerable extent. As already stated in my paper (*Transactions*, March, 1890), I believe the grooved rail to be the best form for city streets, while the trouble from clogging of the groove is probably exaggerated. In some English cities I have seen a water-cart used, which has the wheels set to the gauge of the track, and which has two small pipes leading down close to the ground and delivering a stream of water into the groove of each rail. In other places there are track-walkers with long-handled scoop shovels; a tongue projecting from the front edge of the scoop, fits into the groove of the rail, and as the man pushes the scoop along the rail the tongue slices up and throws out the dirt in the groove. The companies might object to any such extra expense, however small, but the general construction and surface of the street for the use of the public, should be given prior consideration to the desires of the companies. The grooved rail to be used on the Broadway and Third avenue lines in New York, when the cable system is introduced on these lines, is shown in Fig. 21; it weighs 83 pounds per yard; the West End Street Railway Company, of Boston, Mass., is using a girder rail with side-bearing head (Fig. 22). As to the

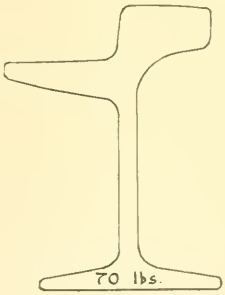


Fig. 22.

Side-Bearing Girder Rail; Boston, Mass.

English girder rail, Mr. Gribble says: "It rests upon a longitudinal bed of concrete, which covers its flanges and maintains it absolutely immovable." In many cases, however, the rails are secured to wrought-iron or steel longitudinals or cross-ties embedded in the concrete, as shown in Fig. 23. That of course is a more expensive method of construction than where the rails are laid only upon the concrete. A

form of rail which is used to a limited extent, is a rolled "box-girder" rail, on somewhat the same principle as the Deas cast-iron box-rail illustrated by Mr. Gribble, but having flanges at the bottom. The rolled rail is 3 inches wide (tread, 1½ inches; groove, 1 inch; guard, ½ inch), 4⅛ inches deep, and 6¾ inches wide over the bottom flanges. Its weight

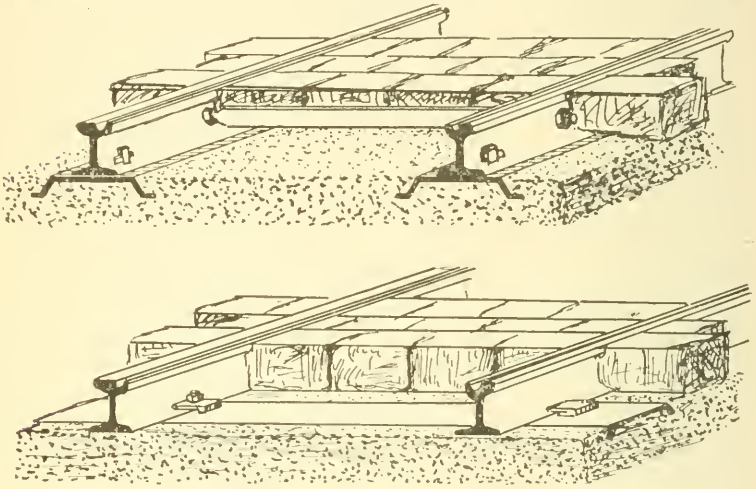


Fig. 23.

European Girder Rails on Metal Longitudinals and Cross-Ties.

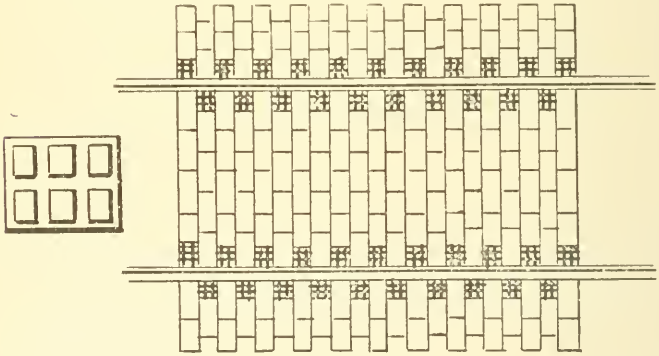


Fig. 24.

Iron Paving Blocks. Scotland.

is from 65 to 75 pounds per yard. At the joints the rail ends rest on a cast-iron plate or chair, about 9 inches square, the outer flanges being held by a lug on the chair, and the inner flange by a bolted clamp. The two chairs are connected by a wrought-iron tie-bar, the ends of which are

turned up to pass through holes in the chairs, and are secured by keys lying in the hollow of the rail. For city streets timber should not be used at all. In regard to the rigidity of the track, which is advocated by the author, some of the English lines are very unpleasant to ride upon, there being a constant vibration and noise in the car. This may perhaps be due, to a certain extent, to the construction of the cars and their springs, but I think a considerable portion is due to a great rigidity of the track. Spiral or transition curves have been tried with success on the Denver and Berkeley Park Rapid Transit Co.'s dummy line, at Denver, Col. Particulars were given in a paper read by Mr. E. L. Woolley, at the Convention of the American Street Railway Association, in October, 1890. (See *Engineering News*, New York, Nov. 1, 1890.)

The ordinary vehicular traffic coming upon street railways has always been a source of trouble, by causing ruts or grooves in the paving along the side of the rail-bed. While in Europe in 1890, I noticed that on some lines at Edinburgh and Aberdeen, there were iron paving-blocks next to the rail, placed alternately with the granite blocks, as shown in Fig. 24; the blocks were about 4 inches by 6 inches, chequered on top. A plan proposed for the same purpose for the Southampton tramways, was to insert thin steel plates in the transverse joints of the granite paving-blocks next to the rails.

In regard to the form of track designed and patented by Mr. Gribble, one feature, which appears to be an objection, is the extreme shallowness of the rail. It is merely a strap rail, without any stiffness in itself, depending entirely upon the key fastenings, to hold it stiff and rigid on the iron and concrete longitudinal. The lug and key system of fastening for rails, promises well; but in this case, the shallowness of the rail necessitates the use of a very large number of keys, to give a practically continuous fastening of the rail. It is a question whether a simpler form of track might not be obtained, by using more metal to stiffen the rail, and less metal in fastenings. For lines with heavy traffic, I should be disposed to prefer a track with saddle or flangeless tee-rails, carried on iron chairs, as illustrated in my paper in the Transactions, March, 1890. The real merits of the flat-rail track can, however, only be arrived at after a sufficiently long test in service, to allow of comparisons being made. It is to be hoped that such a service trial will be carried out, as the general form of the track proposed by Mr. Gribble appears to present some advantageous features.

George R. Hardy, M. Am. Soc. C. E.—I understand that system C is designed for heavy traffic; is there provision enough in the design for extensive wear? It seems to me that after a certain amount of wear, the half of that rail would be worn so thin as to render it dangerous. The question has been raised: If the top wears, why not the bearing also? It requires a large amount of material in the head of a rail to provide

for wear, and to that extent the rail will be much less efficient in proportion than the Sandberg rail would, after a given amount of wear.

Mr. GRIBBLE.—I apprehend that it will wear just as long as the hardness given it enables it to; it will be perfectly safe to give it a great hardness, and the amount of wear upon it can be gauged similarly to any other rail. If an ordinary rail wears too long it is in danger of total fracture, but this rail is supported when worn through because the rolled beams remain intact. The removal of this rail is so simple a matter that it can be taken out and examined, if necessary, after a certain number of years' wear.

Mr. A. J. HUTCHINSON.—I am a practical street-railway man, and I would like to ask Mr. Gribble if he considers that the joint of his rail is properly cared for. I find that the great wear is at the joints, that the decay comes first at the joints; that the rails are sometimes rounded at the ends before the center of the rail is sufficiently worn to throw them out. My experience extends back to about 1854, in connection with the Fourth avenue road. I was there when Mr. Allen Campbell was president of the road, and when the Vanderbilts came in. Probably some of you remember a piece of track laid in Broadway in 1862, between Thirteenth and Fourteenth streets, which I laid. In about 1861 I laid a section of the first girder construction (that is, what you would consider a girder construction) that was ever laid in New York, a single section laid in front of the car depot, corner Centre and Elm streets, where one of your members says the street surface has been so changed by the railroad companies as to make it necessary to change the grade of the street. Mr. Campbell said to me one day that they were likely to lay a track down Broadway, when they would require something to lay on the concrete, and suggested that I get up some form of rail for that purpose, which I did; it had a horizontal base or flange about 12 inches wide, and a perpendicular web of about 8 inches, upon top of which was a form of rail something like the flat-grooved rail of to-day. That was in use about two years, but there came a time when it was necessary to put a side track between the depot and the Tombs building, and it was taken up to make room for the switches.

My experience has been that the wear comes at the joints more than at any other portion of the rail. I am in favor of the railroad T rail; that rail, laid with chairs or with special supports, properly paved on either side, makes a very durable track, and not too rigid. I believe there is such a thing as having too rigid a rail. If it is too rigid there is a pound at the joint. My objection to some patterns of rail is that at the joint the rail and chair are clasped together, which makes a rigid joint at the chair and the tie. The fish-plate joint is not connected with, but separate from, the chair, and is the best joint that I find. I like the idea of using concrete if you will only get rid of the motion of the joint, which

must necessarily come with wear. I like that construction, but with the exception that there is, of course, some give at a flat rail joint, and there is a constant pound under such circumstances.

Mr. JOHN D. ELWELL.—Every effort to improve street railway tracks is confronted at the outset with a difficulty occasioned by expansion and contraction. The constant movement, backward and forward, of the rail cannot be repressed. It must be recognized and provided for by such devices as shall effectually serve to neutralize its mischief-working powers. It is therefore of prime importance in any well advised consideration of street railroad tracks, to first regard them at points at which movement is taking place, and to require, *sine qua non*, that there the structure under the prevailing condition of ceaseless movement, shall be equal to the burden it has to bear. And inasmuch as "strength at the weakest part," is the measure of strength, a street railway should be as strong and in all respects as perfect at its joints, as at any other point.

The value of a joint is, that there expansion and contraction can be provided for. There are no mechanical or other difficulties in the way of lapping the metal of the rails, so that expansion and contraction can take place without the slightest weakness of any kind at the points where allowance for this movement is made. It must however be said, that this can only be accomplished, so far as is at present known, by causing the rail to be its own fish; and with a series of under and over lapping of its parts do away with the necessity of otherwise making a complete break at any point within the length of the track.

This simple alternative is presented: Either the rail is rolled in two webs, and by breaking joints, creates a track that is at each "semi" joint as strong as elsewhere; or the rail is rolled in one web with a complete break at each 30 feet of track, and a weak spot at each joint, in spite of any extraneous connection that has yet been devised, or that apparently can be devised, taking expansion and contraction into account.

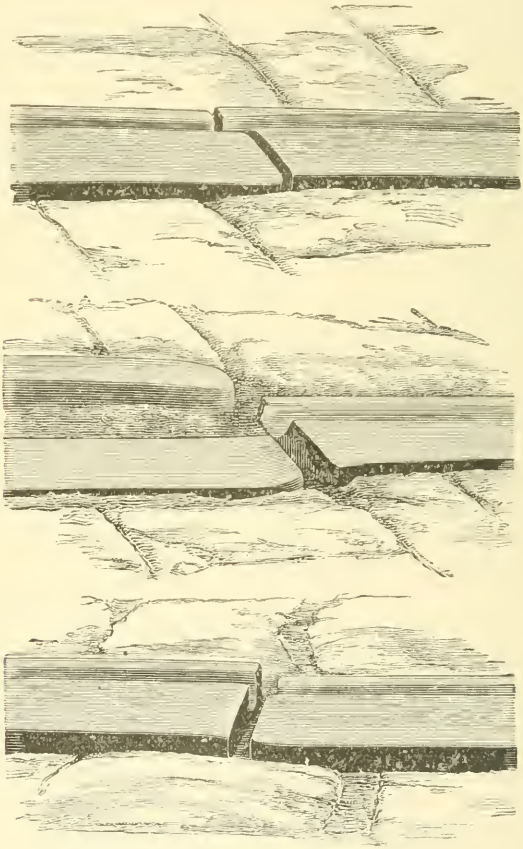
Previous to discussion of road-beds, fastenings, or shape of rail-heads, this fundamental consideration must be determined: Shall the track be a homogeneous whole, woven together so as to obtain unity in all its length, with such provisions for expansion and contraction as to entail weakness nowhere; or, shall the track be composed of unrelated rails, save by an unnatural and insufficient connection, powerless to prevent weakness, at each thirty feet.

Two unqualified assertions are here recorded:

(*a*) No mechanical difficulty exists to interfere with the production of a track, which for all practical purposes is equally strong at every point in its length.

(*b*) No mechanical contrivance exists that can prevent great weakness at each joint of a track made up of unrelated rails, save as they are hitched to each other by longitudinal fastenings.

Adherents of the systems requiring a complete break, so far as the rails are concerned at each 30 feet of their tracks, are naturally puzzled with the question of how best to dispose of their joints, when they have created them. If suspended, they straightway wabb'e with every passing train. If bedded on a metal chair, the chair immediately becomes an anvil for the speedy lamination and destruction of the rail ends. Giving to its metal chair, a curious resemblance to a miniature anvil,



Specimens of Depressed Rail Joints.

was surely a stroke of unconscious humor on the part of the inventor or inventors of the system of clip-fastened track variously claimed in Boston and Brooklyn.

There is a factor in the problem of street railway tracks that does not obtain in steam railway tracks. On steam railways, all the fastenings of the rails and the structure are open to constant inspection, and

the vigilant trackman is perhaps able to "take the stitch in time that saves nine," but on street railways, with everything covered, no such daily correction of "the beginnings of evil" is possible, and every slight irregularity is speedily magnified.

Recognition of this special factor in street railway construction, has led an ingenious official of a well-known Boston Street Railway Company to devise a box with an iron cover, enclosing each joint of his track, which can be opened and the joint connections regularly wound up as one does his watch. His invention is at least a recognition that no non-exposed longitudinal fastenings which have yet been devised, are capable of long withstanding the shocks of electrical traction. Innumerable illustrations of this can be produced. Under the shocks of electric traction, the most recent and carefully constructed street railway tracks exhibit painful evidence of weakness in their low and defective joints, alike destructive to rolling stock and the comfort of travel. The accompanying cuts of the Fourth Avenue Railroad Company's track in Vanderbilt avenue, New York, laid in 1889, are illustrations of the hundreds that might be produced, in demonstration of the incapacity of longitudinal fastenings to properly connect street railway tracks. Such illustrations are daily within the personal observation of any one willing to notice them, and they will be perpetuated and multiplied so long as a radically vicious method of rail connections is adhered to. It may be definitely stated as beyond question, that no multiplication of devices or expedients to postpone the ill effects of this faulty principle of construction can produce results proportioned to expense.

An English fad—fortunately as difficult to introduce into general use in America as the single eye-glass—is a street rail weighing 100 pounds per yard, of which 7 per cent. represents its head-wearing capacity, and 93 per cent. its scrap residue. Discarding all chairs, its broad foot is intended to rest directly on a solid bed of concrete. At the end of six or seven years the rail has reached the limit of head-wear, and the track must be entirely torn up, travel completely interrupted, and a new rail supplied. The scheme has much to recommend it to rolling mills with a surplus product of steel. But apart from the discomfort of riding on so absolutely inelastic a track and its speedy destruction to rolling stock, the short service rendered by the rail for so great an expenditure of material, and the serious annoyance of a complete interruption of travel at its frequent renewals—the track lacks at its best estate homogeneity; and at every 30 feet of its length, vibratory waves set in motion by travel, break with a shock that speedily renders abortive this special effort to perpetuate the device of hitching together rails to form street tracks.

There have been various attempts to unify rails of steam railway track, by dividing their webs into two parts for the purpose of lapping joints. Heretofore such efforts have been on lines incapable of com-

manding success; and all of them for at least one potent reason, namely, that having divided the rails into two webs, they proceed at once to reunite them with bolts and nuts, which inevitably shake loose with the movement of expansion and contraction, and the working and pressure of travel.

In June last, patents were issued for the invention of the bearing of the one web of a divided rail upon the other web with full liberty of expansion and contraction, uncoupled by bolts and nuts. This fundamental principle, therefore, of the duplex lap-joint rail, differentiates the Gibbon system of street railway tracks from any other. It apparently solves the problem of the construction of a street railway track having equal strength, smoothness, and elasticity at every point in its length. Of absolute simplicity of construction, it reduces to a minimum the number of separate metal parts employed to constitute the complete track. As a matter of fact, it employs considerably less than one-half of the number of separate metal parts required by the other system, assembling its maximum number (seven) at the semi-joints, viz.: The 3 parts of the rail—1 chair, 1 tie-bar, 2 lock wedges; total, 7, as compared with the upwards of forty separate pieces of metal assembled at each joint, by one of the most used splice-bar systems of tracks.

The following claims are made for this system:

(*a*) The material can be furnished at a less cost than for any other girder construction, and can be laid at less cost than the track of any other system.

(*b*) The maintenance and repairs are reduced to a minimum.

If the effort to improve street railway tracks is confronted at the outset with the difficulty of obtaining a track equally strong, smooth and elastic at every point in its length, it is next met (such track having been secured) with the problem of laying it to the greatest advantage.

(*a*) It should be laid on a sufficiently permanent foundation to at least avoid any necessity of a renewal of the substructure when the track is renewed.

(*b*) It should be laid so as not to be absolutely rigid, but sufficiently elastic for the ease of travel and the conservation of rolling stock.

(*c*) It should be laid so as to allow of rapidity and economy in repairs, with a minimum disturbance of the street surface.

The use of wood as the substructure of street railway tracks should be prohibited by municipal ordinance, wherever in city streets track has to be relaid. An enlightened self interest should be a sufficient restraint, but at times those intrusted with the management of street railroads are financially interested in pushing "a timber railroad with a capping of iron."

An indestructible substructure, that does not interfere with proper elasticity, and preserves all the strength required to resist vertical and lateral thrusts of traffic, may be obtained by intermittently supporting the

track at not more than 5 feet intervals, on properly constructed metal chairs resting on concrete foundations.

The whole modern bent is toward speed, and it may be set down as definitely settled, that the requirements of elasticity in a railway track are in proportion to the speed acquired.

Nothing is more thoroughly proved, by actual experience, than the unequal wear of the rail surfaces in crowded thoroughfares subject to heavy vehicular traffic. At one point in the line of track, the head of a rail will be seriously abraded. At another point the tram of a rail will be injured. At certain points on the line of track the natural wear of the cars' wheels on the head rail, will be almost the only attrition. At another point, the scraping of the tram by drays will greatly exceed the head wear. Rapidity and economy in repair with a minimum disturbance of the street surface, can be obtained under a system that discards no more of the rail than that part which is injured or worn out.

The following are fundamentals as regards street railway track:

First.—It should possess in the fullest measure the strength, smoothness and elasticity needed at every point in its length.

Second.—It should be laid on an imperishable substructure, so as to fully preserve needed elasticity, for the comfort of travel and the conservation of rolling stock.

Third.—Its design should allow of repairs and renewals with ease and rapidity, and a minimum disturbance of the streets.

A decent regard should also be had for economy at least to the abandonment of all attempts:

(*a*) To wheedle a wrong principle of construction into a proper service by a complication and multiplication of parts.

(*b*) To bully a wrong principle of construction into a proper service by sheer bull-headed superabundance of material.

Minor considerations, such as the shape of the head of the rail, depend largely on special conditions. A good system of track should meet all such requirements and adapt itself equally to side bearing, center bearing and grooved rails.

So also, as to weight of rails; the country road with horse traction does not require as heavy a section, as the crowded thoroughfare with electrical traction; but rails from 38 pounds per yard to 78 pounds per yard may be accepted as the very extreme of desirable weight.

So long as the overhead system of electrical traction obtains, a track that will serve as the medium for the return ground current of electricity without a reinforcement of copper wire at its joints, is much to be desired.

In this respect the duplex lap-joint track possesses the advantage of absolute contact of metal in its entire length, and under such conditions as prevent electrolysis. Its box shape furnishes a perfect vertical wall

for the support of the pavement, and with a permanent substructure, it avoids the absolute rigidity of a track continuously supported by a non-elastic foundation.

If 7 000 pounds is regarded as the maximum weight that in practice is placed upon any one point of a street rail, the duplex rail of weight mentioned by Mr. T. C. Gribble is from twice to four times (according to the spans) stronger than is necessary as regards its working load; sustaining such load at least one-fifth below the allowance of $\frac{1}{30}$ of an inch deflection for each foot span. At from 5 to 2 feet spans it is eight times to twenty times stronger than is required to sustain the maximum weight that in practice would be placed on it, as regards its breaking load. No such weight, therefore, viz., 78 pounds per yard, as suggested by Mr. Gribble, is required in any street. Not even for the heavy vehicular traffic of Broadway, New York.

The duplex lap-joint track is the only system that avoids fatal weakness at the joints, and it therefore alone responds to the fundamental requisite of a good street railway track.

Thomas H. Gibbon.—The agitation which has long existed in the public mind, and also in railway circles, respecting the form of rail that ought to be used and the general construction of street railways, is evidence that the present systems are defective, costly in maintenance and a source of annoyance to the public. Street railways, as a rule, have done and are doing much for the convenience and comfort of the people. They have increased the value of property upon the streets in which they run; but this is offset by the continual tearing up of the streets for repairs and renewals, thus obstructing the public thoroughfare. This is not the fault of the railway companies, but of the systems which have been given them for adoption. The people naturally expected, when they gave these valuable privileges to the railway companies, they would receive in return a track which would give smooth and rapid transit, and at moderate charges, and so designed that the public vehicles could use it. Therefore more than ordinary care should be exercised in the analysis of the various systems now in use, to point out their defects, and devise such betterments as will meet the approval both of the railway companies, and the people. But before we analyze the existing systems, would it not be well to find out what are the requirements that will constitute and make a perfect railway track.

The essentials deemed necessary for this improvement are—

First.—All material used in track construction should be of imperishable character.

Second.—Its design should be simple and its parts few and easy of access, so that the part worn may be renewed with rapidity, and with little disturbance to the street pavement.

Third.—It should not possess more material than is absolutely

required to carry the load for which it was designed, thus effecting an economy in first cost.

Fourth.—It should possess elasticity (not rigidity); this would insure the comfort of the passengers when traveling, and preservation of the rolling stock.

Fifth.—It should possess lateral as well as vertical strength, and be able under any circumstance to keep true alignment, grade and gauge. This would lessen repairs.

Sixth.—It should be free from depressions at the joint, in order that the load which it has to carry may be transmitted uniformly and rapidly, with the least possible oscillation.

Seventh.—It should be of the stringer form, thus giving stability and a firm support for the paving.

Eighth.—The rails should be either side-bearing or grooved, both rails having a broad face surface, so that the public trucks could pass along them smoothly and rapidly. The former would be the best for the railway companies, the latter entailing some expense to keep the groove free from dirt and ice. Either would meet the public requirement, providing they have broad running surfaces.

The various types of rail and foundation material that have been applied to meet the real requirements in connection with street railway construction in Europe, are well described in Mr. Gribble's paper. The paper has much food for reflection, digestion and rejection, but Mr. Gribble has failed to touch upon some very important points in track construction and maintenance, which must be accomplished within the bounds of financial prudence in first cost, coupled with simplicity and economy in repairs and renewals, before either the railway company or the people will be satisfied. He has not dealt sufficiently with the joint connection—the weakest and therefore the most important point in track construction.

Should there be elasticity in a railway track ?

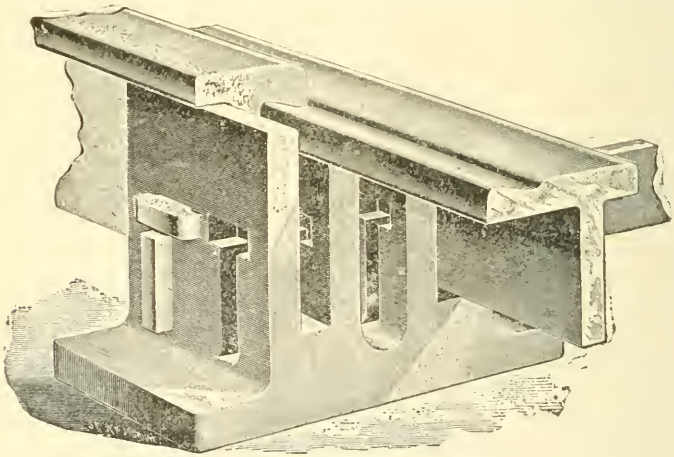
It is a matter of history that railroad tracks were at the first made as rigid as possible, but experience soon demonstrated that such tracks were unpleasant to ride upon and caused rapid deterioration to the rolling stock. Step by step the idea of solidity gave way to that of elasticity, the stone foundations used were discarded, and wood ties with gravel ballast substituted. Even this lacks elasticity under certain conditions, and in winter, under the action of frost, it becomes rigid and even dangerous through unequal bearings, and the consequent breakage of rails.

Metal ties have been found to give all the strength required for steam railway service, and the ballast filling acts as a cushion for easement of travel and preservation of rolling stock. During the past twenty-five years over 12 000 miles of railway track in Germany, Netherlands, Belgium, Austria, Hungary, India and other countries, have been laid with

metallic cross-ties or metallic longitudinal stringers. The first street railway using metal ties in the United States was built in Albany, 1884. In 1889 a report was given by its president. *vide Street Railway Journal*, September, 1889, stating that "It is an easy-riding track, and being smooth there is less noise than on ordinary timber tie and stringer track."

Why a Longitudinal Box Form System should be Used.

Cross-ties bedded in ballast sink irregularly under the action of traffic, partly by compression of the ballast beneath them (to an extent tending toward a limit as consolidation of the bottom ballast progresses), and partly by its being forced out laterally. This detrusion of material from beneath the cross-ties, is effected by pressure combined with vibration and oscillation, acting directly upon those portions of a mass of inelastic and non-coherent material that are in contact with the cross-ties. Mere downward pressure displaces ballast sideways; vibration increases the effect, and oscillation of the cross-ties, by which pressure and vibration are made to act successively in different directions, is yet more effective to produce movement of the particles away from the point at which they are subjected to disturbing actions, as the rail deflects under an approaching load. Weight is first



Joint and Chair in Duplex Rail System.

thrown upon the near edge of the tie, causing it to compress and sink; rising again, the cross-tie has rocked under the load until the far edge has become lower. This rocking motion of the ties displaces the material from the field of downward pressure, hence the low joints and irregular track.

In order to maintain the accurate adjustment to level demanded by the traffic, constant shimming and raising of the track is required, which entails large expense, and becomes impracticable in paved streets.

With longitudinal supports the case is different, the oscillation travels with a wave of deflection, and the effect is to distribute the material lengthwise of the road until equilibrium is automatically attained; therefore there is no possibility of irregular depressions in the track except at the joints, and not even there, if the rails are woven together by lap jointing. It may be said, therefore, that the maintenance of a longitudinal system to accurate level, and consequently to proper line, will be less costly than is the case in the cross-tie system.

Duplex Rail Joints.

The engineering mind in all parts of the world, for years past, has been directed to the solution of the problem of how to connect the rails of a track as to make them practically continuous, and when the fish-plate was introduced, success seemed to have been attained in a high degree; but since the birth of the fish plate the speed of trains has increased, and, with that, such an irritation has come upon even the best fish-plate devices that their life and utility are but of short duration. Let us look for a moment at one of the best fish-plates. We find it can only be connected to the rails by means of four holes (which are destructive to strength of rails), four bolts, four nuts and four washers, making fourteen separate pieces to make this connection. Let us even suppose that drilling holes through the web of the rail, and slotting the flange for the spike, did not weaken the rail. The pressure upon the steel surrounding the bolt holes is so immense, that the best steel can only resist for a short time, friction is caused by every passing train, and the nature of the rail is changed. Each of the fourteen parts composing the fish-plate joint, which were banded together to act as one, becomes loose, and that unity which is required for strength is severed, hence their combined strength is gone, and low joints (always the fruit of weakness), fractured rails and wreck, is the result.

It is well known to managers and practical engineers that the joint is the cause of fully 50 per cent. of the expense of track maintenance, and therefore rolling stock repairs. The trackman's principal labor is in raising low joints. The army of mechanics in the company's shops are largely employed on repairs of engines and cars caused by low joints. The spring and wheels of rolling stock are not broken by gliding on the rail between joints, but by the sudden jarring in crossing over the joints. Now why are there any low joints, when so much material is used? The joint has two plates, weighing from 35 to 50 pounds, besides the nuts and washers needed to secure the two rails together. It would appear at first sight, with all this additional metal, the joint should be the strongest part of the rail, and so it would be if these plates, bolts and nuts were in one solid mass, but they are not, and cannot be put together so firmly—allowing for expansion and contraction—as to make them one; hence the joint is the weakest part of the rail and is

the first part to yield. The chair joint, the narrow fish-plate, the fish and angle plate, the fish-plate and chair combination, all have been tried and found wanting. For proof of this look at our best laid tracks, the joints can be counted by the depressions existing in them, and these depressions cause hammer blows from every passing wheel, and destruction to the rail. In one mile of track we have upwards of 350 joints, which must be closely watched and kept up by some means. Trackmen patrol their sections night and day, screwing up loose bolts and packing up low joints, and yet fail, as the enormous expenses of the repair shops demonstrate. Such is the experience of steam railways. In street railways it is worse, for the ties and fish plates are below the pavement and cannot be got at without tearing it up. This is very expensive and an obstruction to the public travel, hence the imperfect track which now exists. Fifty years of experience demonstrates that the present system of jointing the rails is very expensive, destructive, and very imperfect.

The Form of Rail.

As street railways are made for the people, it is absolutely necessary that they should be satisfied. Does the T-rail satisfy them? The press says no very emphatically. It must go. It has been found dangerous to public traffic, and destroys the pavement. A side-bearing rail with broad tram would be more convenient for public traffic, and its use would reduce the formation of ruts which now exist in the pavement where the T-rail is used.

The systems used in Europe and illustrated in Mr. Gribble's paper show them to lack in virtues which are needed for an economic and serviceable street railway.

First.—They possess excess of material.
Second.—They are too rigid in character.
Third.—The joints are defective.
Fourth.—They are too expensive in first cost.
Fifth.—They incur a maximum cost in renewals instead of minimum cost.

The concrete foundation and heavy grooved rail have been introduced in Washington and Pittsburgh, the track at the latter place costing upwards of $30 000 per mile. The rail has a wearing capacity of only about 8 pounds per yard, which eight years will perhaps wear out, and then will come the renewals. These involve blasting of the concrete to get out the rails, tearing up the streets, and a great interruption to the traffic, all involving expense and a trial of patience.

And now a few words on the American systems, the Johnson, the Wharton, the White, or the Lewis & Fowler systems.

The two former are of the single-girder type, using rails sometimes with and sometimes without bottom flange, fish-plates, chairs, spikes, bolts and timber cross-ties; they are defective, inasmuch as they cannot resist torsional strains, they lose gauge and are weak and defective

at the joint, a difficulty inherent to all splice-bar systems. They are reasonable in first cost, but equally expensive in renewals, entailing a general tearing up of pavement and discardment of all the material, as in the English systems.

The White or Lewis & Fowler system, being of box form, possesses more stability, consequently better gauge and alignment will be kept, but the joint difficulty exists, as in the systems alluded to. It supports the paving better than the Johnson, but does not give a perfect support, as the splice-bars and bolts protrude from the face of the girders at a point too near to the surface of the street; consequently the paving blocks having greater depth cannot come close to the girders of the rails, without the blocks being chipped to fit the bolts and splice-bars. It is more expensive in first cost of material, and uses timber cross-ties, chairs, spikes and splice-bars; and is consequently more expensive in renewals, discarding the whole of the material except about 8 pounds of head wear, and entailing a general tearing up of the pavement to do it. From the rail being in one piece and of box form, it is more difficult to roll, and it is impracticable in anything but a straight track.

The Gribble system (judging from the drawings) is more complex than any of the other English systems. It does not eradicate any of the objections which they possess. It is too massive and rigid; it possesses more material and greater strength than is necessary for street car service. The castings and rails will have to be of the finest fit, so that they knuckle to each other snugly, and even then with no assurance of smooth joints. On the contrary, the rails at their connections will have a tendency to work loose and upwards, on account of the castings not having any absolute anchorage in the cement, which is liable to crack or indent from the hammer blows and vibrations, even of the cars. Again, the lugs on the cast iron girders, which hold the rails in position, being near the surface of the street, are liable to be broken by trucks, and should the pavement be rutted or sunken along the track, these lugs would surely break or become unserviceable (no matter what they are made of), and the rail would become loose. True, not so much metal is thrown into the scrap heap at renewal, but that is almost counterbalanced by the destruction of the cement. The gas pipe tie-bars, have to be screwed up to gauge and kept there, but how I won't say. It may be as expensive in first cost as the English systems, and almost the same in renewals. Some portion of the fixings are imbedded in the cement, and consequently on renewal must be destroyed. This system may have 8 pounds of head wear. The laying and repair involve the employment of a large amount of skilled labor.

The metallic track, laid in November and December, 1884, at Albany, N. Y., was the first all metal system laid in the United States, and does not require spikes, splice-bars, bolts, nuts or rivets. This system is alluded to in Mr. Tratman's paper, already referred to, as "using cast-

iron stringers, filled with sand. * * * * This track has been in service for about four years and has given good service."

It is composed of hollow cast-iron boxes about 6 feet long—open at the top and bottom, having mortises on the ends, to receive the pendant of the rail, and T-shaped mortises on the sides, the vertical part to receive the notched transverse tie-rods (which hold the track to gauge), and the horizontal part to receive the wedge key, which, when driven through the mortises in the castings and pendant of the rail, passes over the tie-rod, and locks all the parts together. The rail was of side bearing section, weighing 40 pounds per yard. In 1889 more track was laid of this system, but instead of filling with sand, the boxes were filled with cement, upon a cement foundation. The verdict was : Too rigid.

In laying this track, longitudinal trenches, about 15 inches wide, were dug for the stringers and transverse treaches for the tie-rods by taking up the paving, leaving the crust of the earth undisturbed. The castings were placed longitudinally in the trenches, 2 feet 3 inches apart, and after being coupled together by the transverse tie-rods, which gauged the track (the rods being notched to the gauge required), were then filled with sand, and tamped, then the rails were dropped into the guides or end mortises in the stringer, bringing the mortises in the pendant of the rails in line with mortises in the sides of the stringer, after which the keys were driven as before described. If care is used in placing the stringers, very little surfacing or lining is required. This system was also laid in December, 1884, in Fulton, N. Y., and on the Southern Boulevard Railroad, New York, in 1888.

The system just described has been demonstrated to possess great merits, but it has the defect of employing cast-iron stringers. The castings are liable to break, and would not be serviceable except in well paved streets; besides there is an excess of metal for the work to be done; the cast-iron stringers weighing 60 or more tons per mile.

A realization of these defects led to the introduction of the "duplex rail" and "lap joint system," illustrated in Mr. Gribble's paper. By it the metal is so distributed as to make a rail and continuous stringer of steel, without any increase of quantity, and its duplex character has solved the "joint" problem. It substitutes for the "fish-plate" or "splice-bar" joint, a lapping of the rail at the joint, the rail becoming its own fish or splice.

To accomplish this, the rail proper is rolled in two distinct parts, the "head" part and the "tram" part. The "head" part resembles the letter T, the tram part resembles angle iron. When these two parts are put together, the head part rests on the tram part, and combined, they form the rail, and three sides of a box, and on top is the side bearing, center bearing or grooved rail, as required. These two parts are arranged, so that there is no complete break in the track anywhere. Where the

head-rails connect, the tram part is a solid support at that point. Where the tram rails connect, the head part is solid above them; practically making a continuous rail. A track thus built, gives equal strength at every point of its length, thus giving uniform elasticity, for the transmission of the loads. It is an "all-metal" system, having metal chairs with large base plates, for the rails to sit in and rest upon. The transverse tie-bars are notched to the gauge required, and the girders of the rail fit into these notches, thus keeping the gauge absolute. The system discards all splice-bars or fish-plates, bolts and nuts, the parts being fastened by a wedge, known as the automatic spring key, which not only locks all the parts of the track together, but also locks itself in. Fig. 25 is a sectional plan of a joint showing the wedges in place.

The following advantages are claimed:

The durableness and permanence of an all-metal system.

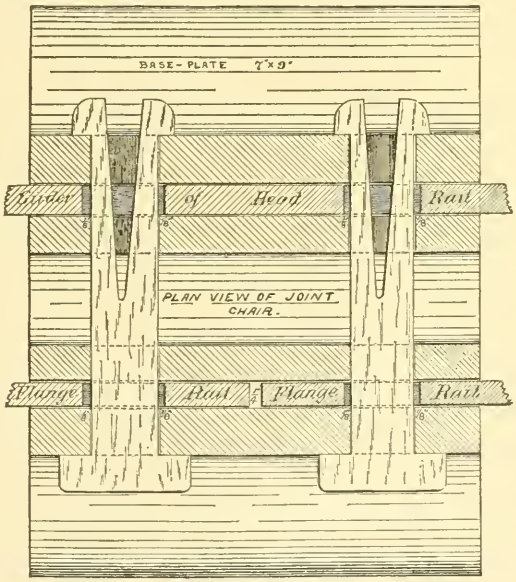


FIG. 25.

The smoothness and stability of a track absolutely free from weak joints.

Increased vertical and lateral strength with no increase of metal.

Freedom from torsional strain—the bearing surface being directly supported by the vertical webs.

Increased wearing capacity of head-rail.

In renewal, the discarding of the worn portion only and not the entire rail.

Perfect alignment and accurate gauge maintained, with required freedom for expansion and contraction.

Simplicity of construction, giving rapidity in track laying and a minimum disturbance of the public streets.

Maintenance of an absolute contact of metal, which obviates the necessity of "bonding joints" in electrical traction.

First cost not greater than that of the Johnson, Wharton, or Lewis & Fowler systems.

H. W. Brinckerhoff, M. Am. Soc. C. E.—In the earlier editions of Trautwine's hand-book is a statement, of which I was reminded by something that was said in the duplex paper on the duplex rail, to which we have just listened. The paper speaks of the necessity of allowing for the expansion and contraction of the rails. The statement was to the effect that it is a remarkable fact, not satisfactorily explained, that when rails, even for a length of several miles, were firmly riveted or welded together, no expansion or contraction during variations of temperature was observed. Of course, it is easy to calculate that if the rail is laid at a mean temperature the tensile and compressive strains due to ordinary variations of temperature will not reach the elastic limit. I wrote, however, to Mr. Trautwine to ask the authority for the statement, and he replied that it was taken from the proceedings of the British Institution of Civil Engineers, and was found in a discussion in which Brunel and Stephenson took part. The fact was not questioned, and the discussion was only as to how it was to be explained. I think a similar case was mentioned in a paper recently read before this Society, where the rails were united by rivets, and the ties covered with turf, and no trouble was experienced from expansion or contraction.

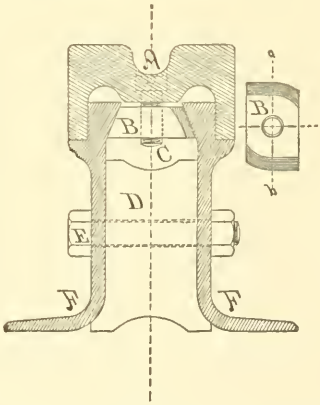


Fig. 26.

Perhaps it may not be remembered by all of us that when the Brooklyn Bridge was being built it was intended to have provided for horse-car tracks on the roadway, and several forms of track were devised for use on the approaches. Among them was one like that shown in Fig. 26: *A* is the rail proper, which has a central groove for the wheel

flanges, and may receive the tread of the wheel on either side. *F F* are supports of rolled iron or steel, which when bolted together, as at *E*, through a cast-iron separator, *D*, form a sort of continuous box-girder.

In laying this track, the substructure, *F F*, etc., is first bedded on a layer of concrete and filled with the same material nearly up to the underside of wedge *B*. Then the wedges *B B* are attached to the rail *A* by the screw-bolts *C C*, whose heads are recessed into the bottom of the groove in *A*, so as to be out of the way of the wheel flanges. The wedges are turned so that the line *a b*, shown on the small plan at one side, is parallel to the axis of the rail, in which position they readily enter the opening between the supports *F F*, but when the screw *C* is turned the square shoulders of the wedge come to a bearing on the inner and inclined surfaces of *F F*, and by turning the screw still further, not only is the rail *A* drawn firmly down to its place, but the pieces *F F* are tightly set out against the vertical flanges of the rail, uniting all three pieces very firmly together. In a well-paved street, gauge-rods are hardly needed, but if desired, the bolts, *E E*, could be extended across at intervals from rail to rail for that purpose.

Some of the advantages of this form of track are: the ability to readily renew the surface when worn, with but little loss for "scrap" and no disturbance of the pavement; the avoidance of fish-plates, and the excellent support for the rail joints, the structure being practically continuous; great vertical strength and lateral stability, together with good support for the adjacent paving.

No tramways were laid on the bridge, however, and so this construction was never used.

Mendes Cohen, Vice-President Am. Soc. C. E.—As it has been stated that rails may be laid continuously, without strains or serious inconvenience from expansion, I may state that on the Baltimore and Ohio Railroad, about thirty-five years ago, the Chief Engineer, the late Benjamin H. Latrobe, designed a three-part rail, consisting of two side pieces and a T-shaped cap included between them, and all riveted together, forming practically a continuous rail. The slots in the cap were cut out oblong, and there was space left between the ends of the caps, so that expansion was supposed to be provided for. The practical working, however, was by no means satisfactory. It was my duty at that time to be engaged upon the locomotives running upon the road, and from my point of view on the engine, I saw a great deal of the trouble. My first experience of difficulty with it was in ascending a grade of 40 feet to the mile with a passenger-train; we came to the siding which the passenger-train should take; but could not throw the switch, which was of the shifting-rail type, then generally used. I got down, and we tried to get the train out of the way, but we found that the rail had stretched to that degree that it lapped over into the casting at the end, and the switch could not be moved. On inquiry of the switchman how he

had allowed that condition to exist, he said: "I have cut off that rail every few days, and I cannot do anything with it; I cannot keep the switch open; when I have cut off the rail on the south side I have added on the other side." It was a fact that, on the 40-foot grade, the one rail had moved to the eastward, or down-hill, and the other to the westward, or up-hill. It was not acounted for at the time. The same rail was being laid at several other points on the road, and at every point where it was laid we had that difficulty. There was no cause satisfactorily assigned for this motion. That it existed, I had no doubt at that time. I left the road within a few months afterwards, and had no opportunity of investigating it, and as the difficulty with the rail was rather a source of annoyance I never heard of its being investigated. I might say, still further, that I have seen from the point of view of the locomotive, the rail actually lifted right up with the cross-ties, somewhat as a wave ahead of the engine, and have seen the broken-stone ballast crowded and heaped up between the ties, as a result of similar movement. There was no question at the time as to the cause of it; it was the unfavorable condition of the rail, so far as expansion and contraction were concerned, and it was found so serious that the use of the rail was given up. I may further say that, when first laid down, so noiseless was the passage of the wheels over it, I have heard it compared in effect to a leaden rail. Such was its condition when I left the service. Two years later I passed over the road and found that the silent track had become a very noisy one from the wear and loosening of the rivets, though they had all been closed hot. A sectional and perspective view of this rail is given by Perdonnet —"Traité Élémentaire des Chemins de Fer," 2d edition, Vol. I, page 492.

Mr. C. B. Fairchild.—I desire to cite a case in point, in regard to laying rails end to end without provision for expansion. A portion of the Georgetown and Tenalleytown Electric Road, built within a year and a half, was laid with T rails, with the ends of the rails absolutely close together. This was on a portion of the line, however, outside the city limits, and the superintendent recently informed me that after putting down the rails they drew the soil up to the rails on both sides, and that they have had no trouble whatever from the expansion and contraction His theory was that the ground kept the temperature of the rail nearly uniform, and it did not seem sufficiently heated to expand to any appreciable extent. Within the city limits, however, the rails were put down with provision for expansion.

Mr. Wm. Richardson.—I cannot say how it is in the vicinity of Washington; but I do know how it has been in this city; where sometimes the thermometer will run up to 90 in the summer and drop nearly to zero in the winter. Tracks were laid in Beach and North Moore streets in this city about the year 1865, and were not used for some time afterwards; and in the summer time, not having space allowed for the expansion of the rails, the string timber was lifted right out of the ground,

the rails getting loose from some of the timber. The result was that the tracks were all drawn out so much that they had to be relaid.

Take, as a sample of the extent of this expansion, the rails of the New York Central Railroad, between Albany and Buffalo; they will measure about a mile longer in a hot day in summer than in a cold day in winter. The result is that we have practically, in laying our street railways with rails 30 feet long, to allow ¼ inch between joints; and that is regularly done by trackmen who cannot perhaps tell you why they do it; but it has to be done, to keep the rails from springing up by reason of lengthening out in hot weather. I think that perhaps it could be obviated with a continuous rail, if we could have one that would not be expanded sufficiently to draw it up from its fastenings; if it was absolutely one rail; but that allowance should be made on rails of 25 and 30 feet in length for that expansion during the heated term, every practical man knows.

R. L. Harris, M. Am. Soc. C. E.—Any one who has had much track-laying to do will not need to discuss this matter of expansion to any extent. It is a curious fact, that upon the original Market Street Railway, in San Francisco, with T-rails, one rail would journey one way and the other the other; it seems partly due to some other reason than expansion and contraction.

Mr. Brinckerhoff.—What was the nature of the rail that crawled in San Francisco?

Mr. Harris.—A tee-rail.

Mr. Brinckerhoff.—That was probably the reason. We all know of the uneasy rails of the St. Louis Bridge, which keep a gang of men busy cutting them off on one end and carrying the pieces around and putting them on the other end.

In this case the trouble is said to be due to the fact that the rail, which is of the ordinary tee pattern, is laid on longitudinal stringers, and in the deflection caused by a passing load, the bottom of the rail is extended while the top of the stringer is compressed; and so the one continually crawls upon the other, causing this curious annoyance, the rails always moving in the same direction as the trains.

The Chair (William P. Shinn, President Am. Soc. C. E.)—I wish to add a word or two on my own account. I have no doubt that the importance of elasticity in track has been exaggerated, that its value has been greatly overestimated. As has been concisely stated by one speaker, elasticity is important where you have irregularities; if you have a perfect track, you do not want an elastic track. I well remember as among one of the early lessons in railroading which I received in my young days, that the locomotive engineers were perfectly sure, and announced it as a result of observation and experience, that they could haul two more cars loaded with live stock than they could haul loaded with coal, because the live stock was elastic. I think in this

you have a demonstration of the character of this so-called elasticity. I hope that our members, and our railroad friends outside of the membership, will devote their attention to getting a perfectly smooth track and not so much to getting an elastic track.

Mr. F. Collingwood, M. Am. Soc. C. E.—For the sake of completeness, I present Fig. 27, showing another rail device for the New York approach of the East River Bridge, which explains itself. The chairs were to be kept in gauge by the bars connected to their bases. The chairs were to be at 5 feet intervals, and to weigh 90 pounds each. The I-beams to weigh 80 pounds per yard. The rails to weigh 55 pounds per yard, and to have a layer of tarred paper between them and the I-beams. The whole height to be 19 inches. A continuous plate, 9 x $\frac{3}{8}$ inches, between the I-beam and the chair, serves for the lower attachment of the hook-headed bolts for securing the rails in place.

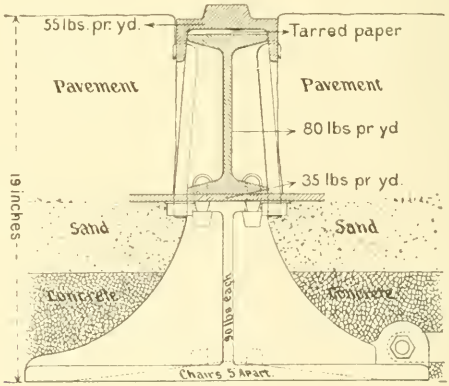


Fig. 27.

Mr. Gribble, in concluding the discussion, expressed his acknowledgments of the kind vote of thanks passed at the reading of his paper, and for all the criticisms upon it, and said, further: With regard to Mr. Tratman's remarks upon the gauge of street railways, it is evident from the figures recommended by the Report of the American Street Railway Association that their object was to enable foreign vehicles to use the rails. This appears to me a practice only defensible, on the ground of the inability of impecunious municipal corporations, to provide suitable roads or pavements for ordinary vehicular traffic, and unworthy of the present financial status of the larger American cities.

It has been a subject of enquiry amongst street-railway men as to why they should have to use heavier rails to carry lighter loads than on steam railways. A letter signed G. H. T. appeared in last month's

Street Railway Journal, showing the position, and appealing for an explanation. I will suggest three:

First.—Because the abrasion of rails on street railways is very much more than on steam railways, largely owing to bad pavements.

Second.—Because in order to obtain an elastic rail and to economize chairs, rails are placed upon double the distance between bearings in cities, of that on steam railways.

Third.—Because rails are designed without sufficient regard for their static stiffness. The same rail-makers exhibit patterns to do the same work, one of which will differ by fifty per cent. from the other in stiffness, and nearly as much in strength. The economic advantage of a continuous support has been already dwelt upon. The counter advantage of elasticity in the rail is not given to us in figures by those who advocate it for street railways, but it may be easily arrived at. Let us take for instance the 78-pound rail, Fig. 18, having no bottom flanges, placed upon bearings 5 feet apart, and regard it as safe under a working load of 20 000 pounds, such as that of au electric car. This rail only does the same duty on a street, that a 50-pound rail of the ordinary flanged tee-section will do upon a steam railway. The chairs are placed upon concrete blocks, and the rail is boxed up with sand ballast. There is, therefore, no elasticity of road-bed, such as is illustrated on Fig. 13. There is only a very slight elasticity in the rail itself, possibly $\frac{1}{35}$ of an inch deflection as against about 2 to 3 inches in the car springs. There is no special virtue about the $\frac{1}{35}$-inch spring of the rail to mitigate shock, more than the same amount of deflection in the car spring. It does not appear sound economy to increase the necessary weight of rail section 28 pounds per yard, in order to provide about one-hundredth part of the total elasticity. If Mr. Gibbon were to enlarge the foot of his rail so as to obtain something of a bulb form, he would, with the same amount of material, obtain a great increase both of strength and stiffness. This, he says, has been done. If, moreover, the chairs were placed 2 feet 6 inches apart, and the rail flanged as on steam railways, the deflection of the rail would be reduced to about $\frac{1}{500}$ part of that of the car springs, and would be absolutely inappreciable. Seeing that all city streets are too hard to give any elasticity of road-bed, and the elasticity of a rail itself is so trifling, these two elements of elasticity may be abandoned. There is, however, a kind of elasticity produced by a support of timber, such as a cross-tie, which assists in mitigating the effect of shocks, more than one of metal or stone. Wood does not spring as much as iron or steel, but it is softer, and absorbs the percussive action like a cushion. What causes the percussive action will be presently enquired into, but it may be said here in advance that a wooden support, whilst mitigating shock at the outset, always ends by increasing it, because it does not spring under the repeated loads; it squeezes, and

apart from its decay, it creates a shock from the unevenness produced by wear, particularly at the joints.

The Wharton system, as carried out at Pittsburgh, consists in laying a grooved flangeless tee-rail having a light web, on chairs 2 feet 6 inches apart, placed on timber cross-ties. Even on so short a span as 2 feet 6 inches, there is percussion in the passing of a wheel over the support, and there would be a gain in using timber, as long as it lasted; but I contend for the principle of a continuous metallic support, as a means of removing the cause of shock itself, and I further claim that the unsatisfactory results with some such systems, when accounted for, confirm the truth of that principle. As several speakers have reiterated, the joint is the weak point of a rail, but it is so because the rail is relied upon, more or less, to furnish stiffness under deflection, as a girder. If, however, the stiffness is all furnished in the support, and if that support is so designed as to have a uniform strength throughout, with no weak point in it, the rail may have as many joints as we please, without affecting the deflection of the structure and without producing shock.

The Causation of Shock.

I will now attempt to sum up the question of elasticity, by enquiring as to the reasons of uneasy riding, otherwise the causation of shock, in street-car travel, about which there is considerable difference of opinion. We are all agreed as to the effects of suddenly applied loads upon rails, especially upon suspended joints. The fan-like bruise betrays the percussion, and the speedy loss of weight the force of abrasion, but we are not so clear as to the cause.

The *rigidity either of a road-bed or a rail* may increase the effect of a shock but it cannot produce it. It is important to distinguish between cause and effect in this particular.

Shocks upon railways arise from an unequal resistance to the passage of the load. If they arise from a weak suspended joint, it is an unequal resistance to deflection. If from the transition from an elastic rail to a rigid support, it is also an unequal resistance to deflection. If from roughness of the rail surface from grit or worn rails, it is an unequal resistance to rolling contact. If from flattened wheels, bent axles or similar defects of rolling stock, it is also an unequal resistance to rolling contact. If from a suddenly applied brake or a sharp curve, it is an unequal resistance to traction.

We do not put springs upon sleighs, although the surface they glide on is often perfectly hard. It is smooth, and offers a uniform and slight resistance to sliding contact. I have traveled at a speed said to be 100 miles an hour upon the "Chemin de fer glissant," the road-bed of which was entirely rigid. No one who has traveled on the "Flying Dutchman," the fastest train out of London, can fail to pronounce it the easiest traveling in that country, but it is upon a rigid track. If we were to put

down a way of polished steel upon a thickness of many yards of solid granite, we could ride upon it in a car without springs, perfectly smoothly; but if we were to place even a sheet of paper on the track, we should feel the passage.

All English tramways are rigid, but no one will contend that they all ride hard. Mr. Tratman complains of some of them, but he does not tell us what their condition was, whether they were clean, and whether they were well laid. All grooved rails are necessarily dirtier than step-rails, and it is surprising how little dirt upon a rail, especially when frozen, will make the most elastic track ride hard; a tight gauge or a rigid car spring will do the same.

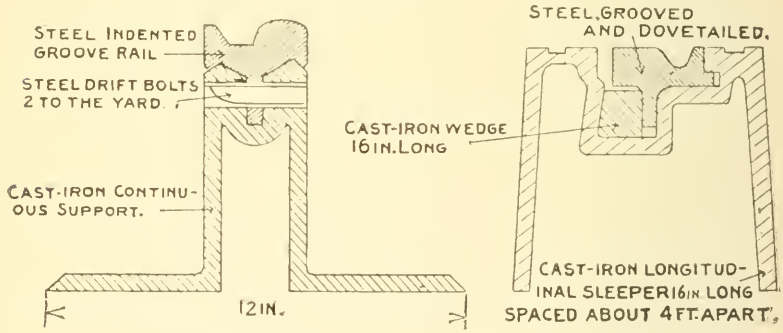
Fastenings.

Mr. Tratman is of opinion that my proposed rail would be better with more depth, with which to provide vertical stiffness, and with fewer fastenings. I will take up this point along with a criticism of Mr. Gibbon's Albany track. I have just stated my reasons, for aiming at obtaining all the required stiffness in the support rather than in the rail, but I go farther. I seek not only a continuous support, but a continuous fastening. There is a vertical movement in a weakly fastened rail, even upon a continuous support, as for instance, the ordinary flat rail spiked down to timber stringers. The rail begins to chatter long before it actually breaks its hold, and there must be an imperceptible vertical movement long before even the chattering begins. It is here that my object has been to get at the origin of the evil and obtain a fastening which will be practically continuous, and so constitute the rail a mechanical unity with its support. I further arrange the key-seats so that distance pieces can be placed between them to prevent any one wedge from starting without first starting the whole series; and as the taper of half the wedges is in the opposite direction to the other half, there is an absolute impossibility for any one wedge to start. In Mr. Gibbon's Albany track the keys are not wedges; they are thin plates of iron which pass through the sleeper and the web of the rail, but the resistance to vertical movement is only in the direction of the least dimension of the key. There is a leverage against the key, of half the width of the sleeper, and the web of the rail must act upon it like a man springing upon a spring-board. The sleepers are only semi-continuous, so that as the load passes from the unsupported portion of the rail to the sleeper it must produce percussion; and as the sleepers are not anchored, I should imagine that unless secured by the adjacent pavement, there would be some likelihood of displacement.

Mr. Gibbon terms his present system a development of the Albany track, but it appears to me a departure in principle from it and a virtual abandonment of his first ideas. The tendency of his remarks is to discourage us from attempting to employ a continuous metallic support on

account of its costliness, and from using concrete on account of its rigidity. I think that Mr. Gibbon's difficulties with the Albany track are instructive, but in a different way. The Albany track resembles in some respects the Cockburn-Muir track shown on Fig. 28. That has also a semi-continuous metallic support, but it has a longitudinal key which wedges up the web of the rail hard against the side of the sleeper. This wedge is as long as the sleeper, and has been very satisfactory. The rail, in addition to this, has a dovetail or lip which fits into a corresponding seat in the sleeper. This is a very superior fastening to the Albany track. In one respect Mr. Gibbon's track resembles the Barker rail shown on Fig. 28. There the support is continuous, and the fastening, like the Albany track, is transverse; but the rail is indented so as to preclude lateral movement, and the key resembles a drift-bolt, having a taper by which to draw down the rail to a firm bearing. This is also a very superior fastening to that of the Albany track. I have ridden in Manchester upon the Barker rail, and can speak well of it. The only improvement made upon it by the inventor has been to double the number of fastenings. Both the Cockburn-Muir and the Barker systems, have

Fig. 28.



Barker System. Cockburn-Muir System.

been proved successful on a large scale, and for many years. They both employ concrete, although they do not obtain from it any material anchorage, they only use it as a foundation. Both sections, like those of both Mr. Gibbon's tracks, lack the lower flange, and consequently do not obtain the greatest efficiency possible from the material. The Barker rail does not need stiffness, because it is continually supported. The web is of no use except for purposes of attachment.

The Albany track, like the Cockburn-Muir, is upon a semi-continuous support, and, therefore, requires vertical stiffness between the sleepers. When the former was tried with concrete filling in the sleepers, the verdict, stated with judicial brevity, appears to have been, "too rigid," and the inventor to have bowed to the verdict. I am disposed

to hazard the opinion that the reason was not that the supports were too rigid, but that the rail was too elastic between those supports—partly from its section and partly from its attachment—and so when passing from a yielding rail to a rigid support, the result was a jarring sensation.

Anchorage.

Coming to the subject of anchorage, Mr. Gibbon criticises my rail as having no absolute anchorage in the concrete; and as that is one of the points I have aimed at more than any other, and without which I should feel that I had made no improvement, I will illustrate the anchorage that I obtain by the application of my rail to cable roads. See Fig. 29.

Arrangements for Cable Roads.

4 feet 8½ inch gauge, with rolled slot-rail and granite paving.

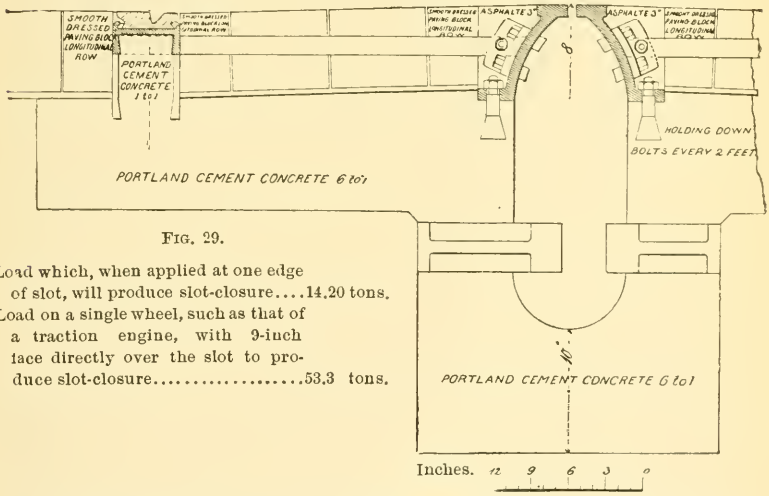


Fig. 29.

Load which, when applied at one edge of slot, will produce slot-closure....14.20 tons.
Load on a single wheel, such as that of a traction engine, with 9-inch face directly over the slot to produce slot-closure.....53.3 tons.

The anchorage is obtained by the cohesive strength of the cement and the tapered form of the metallic sides, combined with the transverse web. To withdraw one of these boxes from its foundation would require on a length of 12 feet about 100 tons, so that practically the box would carry away with it the whole foundation before parting company. It is a simple application of the familiar device of a "Lewis bolt" for lifting large blocks of masonry.

The result, as applied to maintaining a slot-rail from closure, is given numerically upon the illustration, and I see no reason why the entire yoke system should not be dispensed with under this method.

In conclusion, I regret that I am unable to reply to all the criticisms which have been made by Mr. Gibbon. I think that most of them, as

for instance the precaution adopted for protecting the lugs in the last figure, will explain themselves by a close inspection of my different illustrations.

I have explained the principles upon which I have been seeking to produce some improvements in street-railway track. Whether my ideas are correct or not will have to be proved by actual test, which I hope to make as soon as the weather permits.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

465.
(Vol. XXIV.—March, 1891.)

ON THE PERMANENT EFFECTS OF STRAIN IN METALS; ON THEIR SELF-REGISTRATION, AND MUTUAL INTERACTIONS.

By ROBERT H. THURSTON, M. Am. Soc. C. E.

Some years since the writer was very much interested in the various phenomena illustrating a singular molecular habit of the metals, when subjected to stress exceeding their elastic limits, and which results in permanent deformation, all of which phenomena seemed to have important practical bearing upon the work of the engineer, and the safety and the life of his structures. A number of minor investigations were at that time made by him and recorded in the papers which may be found bearing his name in the *Transactions* of the American Society of Civil Engineers of that time.*

In a paper read December 6th, 1876, the writer gave an account of experimental investigations leading to the determination of the "rate of set of metals subjected to strain," and showing both an observed decrease of resistance at a fixed distortion, and an increase of deflection under a

* See *Transactions*, March and April, 1876; January, 1877; March, 1878; May, 1880.

fixed load. It was then shown that certain important modifications of the strength and ductility, and of the molecular characteristics, of metals were produced by modifications in method and time of loading, and it was shown both that the ultimate resistance might be increased by a long period of loading, and that a member loaded to a point far within its breaking limit, as indicated by ordinary test, might yet be fractured by the lesser load, if sufficiently long subjected to it. A marked difference in the behavior of iron and steel as compared with most of the alloys was observed, and it was concluded that they constitute a safer class than the latter. It was also concluded that the "iron-class" might be expected to carry indefinitely, at least far beyond the elastic limit, loads to which they had been found equal by test, however long the time of action. This latter conclusion has since been found to be less general than was then supposed, and experiments since made, and others in progress, indicate that this safety is limited to cases where the factor of safety is at least 1.5 and perhaps even 2.*

In a paper read before the same society, March 20th, 1878, a "new method of detecting overstrain" in metals of the "iron-class" was described and discussed, with an account of the experiments leading to its discovery, and with illustrations of some of its many important applications in practice. It was shown that "a metal, once overstrained, carries permanently unmistakable evidence of the fact, and can be made to reveal the amount of such overstrain at any later time with a fair degree of accuracy." It was shown that this evidence cannot be destroyed by any known method, even heating and annealing only obscuring without extinguishing it. The main fact of this case is that the elastic limit found by ordinary test, in any piece of iron or steel, is the record of the maximum stress to which it had at any time previously been subjected; whether by accident or in the process of manufacture. If low, and at the usual limit, it indicates the maximum stress exerted in the process of rolling or working into the final shape; if high, it is usually the result of some subsequent accident or otherwise produced overstrain. It was shown how this fact might perhaps be sometimes made useful in the discovery of the method and causes of the breaking down of bridges or of machinery.

In another paper, read April 7th, 1880, the writer showed the fact of

* Iron and Steel; Vol. II; Materials of Engineering; R. H. Thurston, especially Chapter X, Article 295.

the production of changes of molecular condition and of stress and strain in all directions by the action of any force appreciably straining the piece, and acting in any one direction, whatever that direction might be; resistances being increased to all directions of strain by strain in any one direction. This "variation of the resistance due to orthogonal strain," and variation of the elastic limit in every direction by such straining, was described as revealed by the researches of the writer, and some of its more important applications were suggested and their value indicated. "Iron and steel rods broken by tension were found to have their transverse elastic limits abnormally elevated, and to have become very stiff and of comparatively slight ductility." Lateral compression, as by cold-rolling, produced "great increase of strength and stiffness, and an even more considerable exaltation of the normal elastic limit. Torsion similarly stiffened wires and rods longitudinally; and test-pieces longitudinally strained became stiffer against torsionally and transversely applied stress." It was concluded that "thus orthogonal strains mutually affect orthogonal resistances of metals; and the engineer is by this fact compelled to study these mutual influences in designing structures in which the stresses approach, or may exceed, separately or in combination, the normal primitive elastic limit of his material." Many illustrations of such phenomena were described and illustrated by the figures obtained by test, and by the curves produced by plotting the results given and tabulated.

The principle thus revealed, and which is likely to prove of such importance to the engineer, may be enunciated thus:

If a metal be subjected to a stress of any given kind, or in any stated "sense," sufficient to produce permanent strain and set, then its ultimate resistance to that, or to any other kind of stress, will be sensibly increased, and in all directions, whatever the line of action of the deforming stress.

Mr. George W. Bissell, in charge of the work of instruction in the Sibley College laboratories, has illustrated this principle by the following series of striking and suggestive experiments:

Four series of experiments were planned, in each of which the material employed was subjected to strain in either tension, compression, torsion, or by transverse loading; and the application of another straining force was then made to reveal the permanent effect of the first, and the altered elastic limit and ultimate resistance.

For convenience the several series have been designated as *A*, *B*, *C*, *D*; and the specimens have been numbered consecutively from 1 to 16.

The material used in all of the tests was machinery steel (0.5 *C*).

(1.) Series A.—Four test-pieces, ¾ inch diameter, 14 inches long, were prepared by turning in each at the middle of its length a neck, ½ inch diameter and 2 inches long. One piece was tested by tension until a decided set was obtained. A second piece was bent in the neck, straightened and then bent and straightened again in a plane at right angles to that of the first bending.

A third piece was twisted forward and back between the centers of a lathe (the ends being dogged to the face plate and tail-stock, power being applied by the driving belt twisted the specimen). The fourth piece was compressed until decidedly bulged in the neck.

This neck served in all cases to localize the stress.

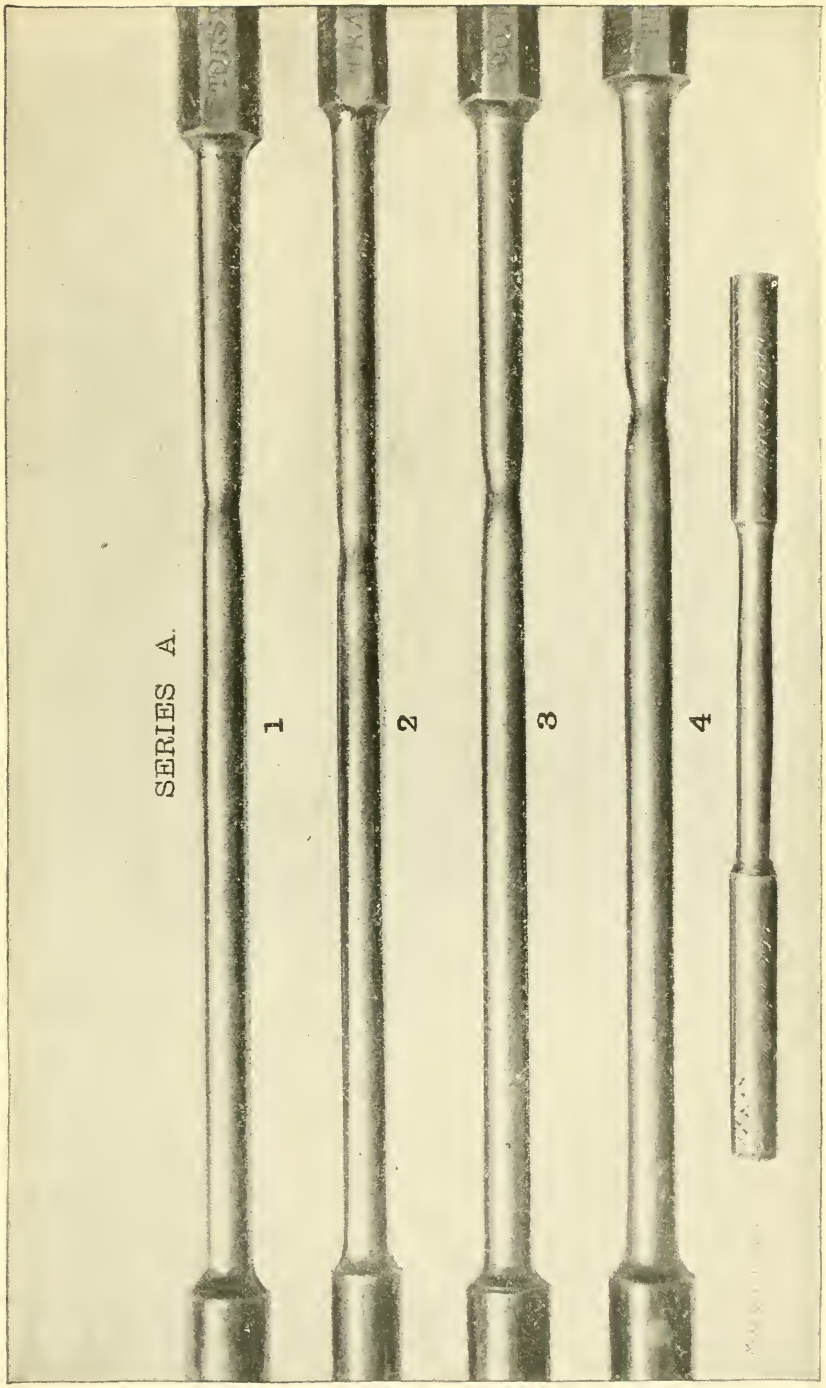
The four specimens were then turned to an accurately uniform diameter, somewhat less than that of the previously strained part, for a length of 10 inches. Finally the four pieces were pulled in the testing machine until a decided neck was formed.

It was then observed (see Nos. 1–4) that the previously strained portion was, in each case, of greater diameter by a visible amount than any other part of the specimen, the "neck" having formed near one end; thus showing increased resistance to tension in the strained section and decreased ductility. (See Plate XIV.)

Below are tabulated in thousandths of an inch the diameters of various parts of the several test-pieces :

SERIES A.

No.	Diameter At		
	One and a half inch Left of Middle.	Middle of Strained Section.	One and a half inch Right of Middle.
1	479	526	475
2	452	477	449
3	474	486	465
4	500	524	495


SERIES A.
1
2
3
4

(2.) SERIES B.—Five torsion test-pieces were used. One was turned to standard size and broken in the Thurston "Autographic" machine, a diagram being taken.

Another was made with extra long shanks and turned down at its middle to $\frac{3}{4}$ inch diameter and $\frac{3}{8}$ inch between shoulders. This piece was strained by tension until a decided set was noticeable. The three remaining pieces were reduced at the middle by turning to $\frac{3}{4}$ inch diameter and $\frac{3}{8}$ inch long, and were subjected one each to severe compressive, torsional and transverse stresses, in each case obtaining a permanent set.

The four specimens were then converted into standard torsion test-pieces and were tested to rupture by torsion, diagrams being obtained on same sheet with the first set from the same specimens. The curves showed increased resistance and decreased ductility, and the specimens, when etched to show the disposition of the fibers, displayed on each helices of different pitch; the more oblique being upon the parts strained but once and the less inclined upon the maltreated portion. The pitch being proportional to ductility, we see at once the effect of maltreatment upon this property of the material. (Plate XV.)

The phenomenon is most marked in Nos. 7 and 5, which were originally strained by compression and flexure respectively, but is nevertheless apparent in the other cases upon the specimens themselves.

(3.) SERIES C.—Four pieces, 4 inches long by $\frac{5}{8}$ inch diameter, were prepared by turning each near the middle section to a diameter of $\frac{7}{16}$ inch for a length of $\frac{3}{16}$ inch. These pieces were strained severely by tensile, compressive, torsional and transverse stresses respectively, and from each was cut a compression test-piece, $\frac{3}{4}$ inch long by $\frac{3}{8}$ inch diameter, in such a way as to bring the maltreated portion in the middle of its length. These were finally subjected to high compressive stress and with the same interesting effect in all (Nos. 9–12), viz., much larger diameter at the ends than at the middle section. The pieces tended to assume an hour-glass shape. (Plate XV.)

This result indicates increased strength and decreased ductility in the maltreated parts.

(4.) SERIES D.—Four bars, 8 inches long by $\frac{5}{8}$ inch diameter, were centered, and in each was turned a neck, 1 inch long by $\frac{7}{16}$ inch diameter; the same being located wholly to one side of the middle, *i. e.*, 4 inches from one end and 3 inches from the other.

The several bars were then subjected to the four kinds of stress, the same being, as before, sufficient to give permanent set. Then they were turned down to about $\frac{5}{16}$ inch diameter over the whole length and subjected to transverse stress applied at the middle, which was also the middle of the supported length of 6 inches. As the force was applied the bar was seen to bend almost entirely on that side of the middle which had not been treated. In one or two cases the previously strained half was perfectly straight (Nos. 13–16). In the figures the points of application of the force and of support are indicated.

Thus, by a series of "qualitative" tests, the results of which are visible to the unaided eye, the proposition was demonstrated.

It was desired to make this set of specimens more complete by adding a similar set obtained by similar experiments upon other metals than iron, but owing to the commonly accepted theory of the effect of time stresses on the brasses, it has not until lately been thought probable that the above experiments could be repeated upon brass with satisfactory results. However, while preparing this paper, an experiment upon a piece of brass was made by Mr. Bissell according to the method indicated in Series A, and the result is shown in the photograph of the specimen (No. 4, Plate XIV).

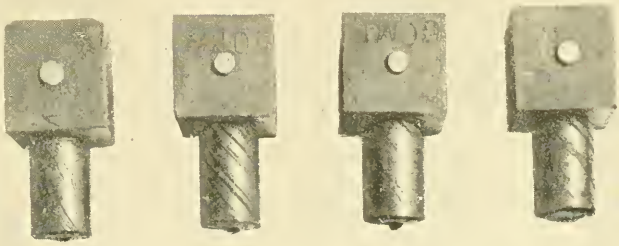
The conclusion is, obviously, that it may be possible to detect in brass a behavior similar to that of iron in this respect, which is what might be expected if strains caused by wire-drawing can be modified, if not removed, in both classes of metals by annealing.

This latter discovery thus made by Mr. Bissell will probably be considered of sufficient importance to justify its publication in this manner.

DISCUSSION.

J. B. Johnson, M. Am. Soc. C. E.—Such facts as are presented here do not strike me as being particularly new, but they are none the less important for that. It has been well known, it seems to me, to all investigators in metals, that cold working of any kind increases the strength of the metal to a material extent. I have shown myself, that cold drawing of 50 000 pounds iron, up to 45 000 pounds or up to rupture, giving it a period of rest and testing again, will increase the strength of the iron to about 70 000 pounds; and these facts are given in the standard publications, as well as in Society papers. The strength, however,

SERIES B.

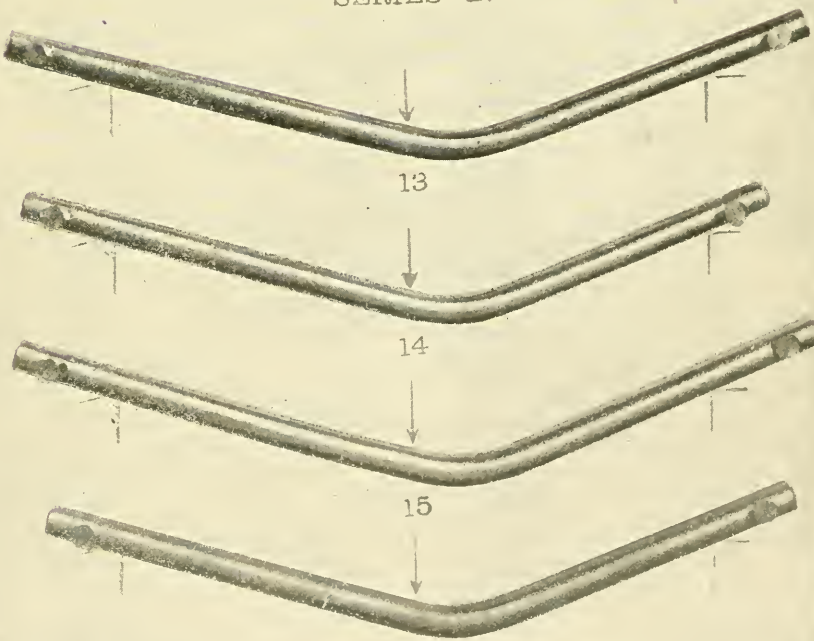


5 6 7 8

SERIES C.

9 10 11 12

SERIES D.



13

14

15

16

increases with the time of rest. If 50 000 pounds iron be tested to rupture, and a broken end of the same piece be broken again after one day, it will run probably to 58 000 pounds; if it be broken in one week it will go to over 60 000 pounds; if broken in three weeks it will probably break at about 62 000 pounds, so there is a time effect;* what the nature of this effect is, would be a very interesting subject for study. We know, too, that the effect of cold bending would be to increase the strength. When you take a piece of soft wire and try to break it by bending, you bend it one way and try to bend it back again, it bends somewhere else. So you take a piece of soft iron wire and pull it or stretch it away beyond its elastic limit, and it strengthens it. It seems to me we have observed the same effect in the bending of tin; it is very difficult to straighten bent tin, it bends back in another place and you get another bend; this illustrates almost as well as any other experiment, that the character of the material, at that point, has been changed. Pulling a piece of iron in the testing machine is nothing more or less than a process of wire drawing. If you put it in a compression machine and crush it beyond its elastic limit, it is nothing more or less than cold rolling. So that all these facts, it seems to me, are well known in certain ways, while they may not have been granted by every one as general principles. Engineers will usually say, when engineering materials have been tested beyond their elastic limits, they are injured and must not be used, or, that iron which has been strained beyond its elastic limit must no longer be used. It is important that these points should be discussed. Inasmuch as these are facts, and universal facts, why should engineers insist constantly that when a piece of iron has been strained beyond its elastic limit it has been permanently injured? We do not think wire is a dangerous material to work with; we think iron or steel wire a very good material to build structures from, and no one hesitates to endorse the Brooklyn Bridge because it is built of wire; all that wire has been stretched away beyond its elastic limit. We do not know what the elastic limit of steel which is rolled at an unknown heat is, the colder it is the higher that limit. If a piece of 50 000 pounds iron be stretched to 45 000 pounds, then 45 000 pounds is its elastic limit; for all practical purposes we call it perfectly elastic up to the limit of its previous loading. It makes the product rather more certain in its qualities and more readily determined, and rather more constant; and its strength, as in iron, may be increased 20 per cent. Therefore I would like to know why we should continue to insist that a material is injured when it is strained beyond its elastic limit.

F. W. Skinner, M. Am. Soc. C. E.—There are one or two points that suggest themselves to me, from Professor Johnson's remarks with regard to the benefit of straining metal beyond its elastic limit, and the advisa-

* See paper by the writer before Engineer's Club, St. Louis, in Jour. Assoc'n Eng. Soc's, Vol. VII, 1887, p. 98, giving experiments.

bility of afterward using it. Most of us are familiar with the experiments relating to the destruction of metal by the repeated application of the same strain. It is agreed that it endures an unlimited number of strains, if they are restricted to a district considerably below the elastic limit; whereas a much less number of applications nearer to, or above that point, and below its original breaking load, will destroy the metal. I think that this is a very important consideration in designing all our structures.

With regard to the improvement of metal by a strain beyond the elastic limit, Professor Johnson instances wire. I think there can be no doubt he is right about that, but I do not see how it is applicable to any structure that we have to deal with. Elementary members, much less girders, trusses, etc., cannot be commercially strained up to the elastic limit by any machines now in existence before they are put in the structure; if, afterward, when the structure is completed, they are tested to any such degree as that, they by the very definition of elastic limit—as the point where permanent set begins—would suffer irremediable distortion, causing or hastening destruction. I think that that would preclude the application of this principle in this case. Then, again, when we strain structural material beyond the elastic limit, we develop and increase latent flaws which are not apparent or are insignificant, and which might not otherwise amount to anything, and make, possibly, slight imperfections to become a great danger, though still concealed.

Professor Johnson.—I do not want to go on record as recommending working structures up to or beyond their elastic limits, it was only the question of a single stress beyond the elastic limit injuring the material. I would not for a moment recommend using any higher stresses than good practice now endorses. Take a chain, for instance; I believe that a chain when tested for strength, is benefited if it is pulled out beyond its elastic limit. It is then in a condition of perfect elasticity up to the load we have used. We have, of course, taken out of that material a certain amount of its total resilience. We have probably diminished its capacity for repetition of load; that is, if it is going to be worked till it fails at repeated heavy loads, it probably will not do as much work after we have stretched it beyond the elastic limit as it would have done in the beginning. It is simply a question whether engineers ought to be a little nervous about using a material for nearly static loads, which has been strained beyond its elastic limit.

Mr. Skinner.—Do you refer to steel as well as iron?

Professor Johnson.—Yes.

Professor H. T. Eddy.—It seems to me that Professor Thurston has called attention in this paper to a matter of great interest to us all, viz., to the manner in which metal is affected in several directions by a strain in any single direction.

If, for example, we roll or hammer a piece of iron, cold or hot, we

thereby squeeze it out sidewise, and elongate it in directions at right angles to the force applied by the rolls, and its moduli of elasticity as well as its ultimate strength in these directions have been changed by the process. The value of this paper lies in the fact that by a series of carefully devised experiments, Professor Thurston has clearly demonstrated the actual existence of what has too often been regarded as a theoretical abstraction which might be safely neglected by the practical man.

In view of this, permit me to review the fundamental theoretical relations existing between deformations and the forces producing them, or, in more precise language, the theory of stresses and strains. The method by which the equations expressing the relations between the stresses and strains in an elastic solid are established in most of our text-books, although it has been employed by almost all the more important writers upon this subject, such as Poisson, Navier, Lamé and others, is, nevertheless one which has in it obscurities that constantly lead to doubt and erroneous conclusions, respecting the behavior and actual properties of elastic material subject to stress.

The labors of Stokes, and of Thomson and Tait, have put the fundamental conceptions which furnish the basis of these equations in a new and clearer light. This new method of establishing these relations seems not yet to have attracted the attention of engineering writers. It shall, therefore, be the object of this discussion to give an exposition of the subject, which, without following closely any previous presentation, shall nevertheless embody the improved method, and be drawn out in such detail as to give a clear insight into this theory, upon which accurate conceptions are of importance in designing engineering structures.

Every solid, whether perfectly or imperfectly elastic, necessarily exhibits two distinct kinds of resistance to deformation. In the first place, it offers resistance to change of volume. Fluids as well as solids offer resistance to compression, *i. e.*, diminution of volume, but solids resist dilatation also, and in such a way that the proportionate change of volume within elastic limits, is almost exactly the same for dilatation as for compression. The cubic compressibility of wrought-iron is seventy or eighty times as great as water. A piece of iron or other material can be subjected to this kind of stress by being put under hydraulic pressure in a fluid.

A second kind of resistance to deformation, called rigidity, is developed when forces are applied which tend to make one part of a solid slide on that beside it.

Perfect fluids have no rigidity, and offer no resistance to forces applied in this manner. Viscous fluids are somewhat rigid, at least for rapid changes, but do not recover their shape when distorted in this way. Force distributed over a surface in such a way as to tend to make one part slide on the other, is a shearing force or shearing stress, and the slight elastic displacement which takes place is a shearing strain. The

rigidity of the various elastic solids, differs greatly. India-rubber, for example, has little rigidity compared with most solids, the rigidity of iron is many hundred times as great, but the cubic compressibility of India-rubber is nearly the same as water.

The physical character of an elastic solid, so far as concerns its elastic properties, is completely determined by its behavior under these two kinds of stress. It has been assumed by some, that these two kinds of elasticity have a fixed relation to each other which is the same for all bodies, or at least for all metals; but such is evidently not the case; for, as has been stated, the compressibility of iron exceeds that of rubber many times, while the amount which iron will yield to a shearing stress is an exceedingly small fraction of the yielding observed in rubber.

When a solid is subjected to direct compression under hydraulic pressure, it may be such on the one hand, that every straight line which is supposed to be drawn in the solid is shortened in the same ratio, or, on the other hand, it may be that the solid is more compressible in some directions than in others. This last kind of structure or texture, may be thought to be especially the case with crystalline bodies. So, too, the rigidity of a body may be different in different directions. For the present, only those bodies will be treated which are alike in all directions; such bodies are called *isotropic*, to denote this property.

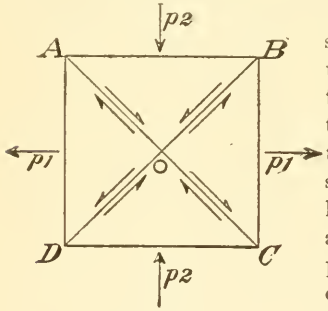


Fig. 1.

In order to comprehend how an elastic solid is deformed by forces applied in the usual manner, *i. e.*, in certain given directions, it is necessary to show how a simple tension or compression in a single direction, can be replaced by an equivalent system of stresses consisting only of hydraulic pressures, positive or negative, and shearing stresses. To this let us now proceed. For convenience, let the stress of the first kind, which consists of a uniform pressure or tension in all directions, be called a solid stress, and be regarded as positive in case it produces tension, and negative in case of compression, so that ordinary hydraulic pressure is negative.

It is to be noticed that in a shearing stress the forces acting are all parallel to one plane, and so it is a plane stress, and would act as does a couple, to turn the body about an axis perpendicular to the plane of the stress, were it not held in equilibrium. The only way it can be thus held in equilibrium without affecting its own intensity, is by another shearing stress parallel to the same plane and of equal intensity, tending to turn the body in the opposite direction, but distributing over planes at right angles to the first-mentioned shearing stress.

The relations of these two shearing stresses in equilibrium is shown

in Fig. 1 as acting along the diagonal planes of the cube $A\ B\ C\ D$, forming part of the interior of the solid.

Suppose the intensity of the shearing stress in each diagonal is p per square unit, and consider the forces acting upon the prism $O\ B\ C$ which is one quarter of the cube.

In order that $O\ B\ C$ may be in equilibrium, a normal stress p_1 must act on $B\ C$ of an intensity equal to p; for the total force parallel to $A\ B$ on the faces $O\ B$ and $O\ C$ is $(O\ B + O\ C)\ \frac{p}{\sqrt{2}} = B\ C\ p$, which force must be balanced by $B\ C\ p_1$ acting on $B\ C$. $\therefore\ p_1 = p$. Similarly it may be shown that a normal stress $p_2 = -p$ must act on $A\ B$. In other words, the state of stress induced at any point of the solid by the action of a pair of shearing stresses in planes at right angles, is equivalent to a compression and a tension of the same intensity, applied to planes bisecting the angles between the planes of shear; or *vice versa*, a tension and a compression of equal intensity on planes at right angles, is equivalent to a shearing stress of the same intensity on each of the planes bisecting the angles between the planes at right angles.

Again, let us consider a portion of an elastic solid in the form of a cube whose edges are parallel to a system of rectangular axes x, y, z. Let a uniformly distributed stress of intensity p_1 act parallel to x in opposite directions, on the two faces perpendicular to x; and let p_1 be positive for tension, negative for compression.

The stress p_1 may be regarded as compounded of a uniform solid stress of intensity $\frac{1}{3}\ p_1$ on each of its six faces, together with two shearing stresses, as follows: One consisting of a stress of $\frac{1}{3}\ p_1$ along x and $-\frac{1}{3}\ p_1$ along y, the other of a stress of $\frac{1}{3}\ p_1$ along x and $-\frac{1}{3}\ p_1$ along z. This separation of the simple stress p_1 along x into component parts which are together equal to p_1 may be exhibited for convenience in tabular form, thus:

		1	2	3
Stress along	$x =$	$\frac{1}{3}\ p_1$	$+\ \frac{1}{3}\ p_1$	$+\ \frac{1}{3}\ p_1$
" "	$y =$	$\frac{1}{3}\ p_1$	$-\ \frac{1}{3}\ p_1$	$+\ O$
" "	$z =$	$\frac{1}{3}\ p_1$	$+\ O$	$-\ \frac{1}{3}\ p_1$

The stress in column 1 of this table is a solid stress; that in column 2 is a shearing stress whose planes of shear are the diagonal planes of the cube which mutually intersect in the axis of z, and so bisect the angles between the remaining axis x and y. A similar statement holds respecting column 3.

Again, if p_2 act along y, it can be separated into three component states of stress, as shown in the following table:

		4	5	6
Stress along	$y =$	$\frac{1}{3} p_2$	$+ \frac{1}{3} p_2$	$+ \frac{1}{3} p_2$
" "	$z =$	$\frac{1}{3} p_2$	$- \frac{1}{3} p_2$	$+ O$
" "	$x =$	$\frac{1}{3} p_2$	$+ O$	$- \frac{1}{3} p_2$

The stresses in this table form one solid stress and two shearing stresses, as in the previous table.

And, if p_3 act along z, it may also be separated into a solid stress and two shearing stresses, thus:

		7	8	9
Stress along	$z =$	$\frac{1}{3} p_3$	$+ \frac{1}{3} p_3$	$+ \frac{1}{3} p_3$
" "	$x =$	$\frac{1}{3} p_3$	$- \frac{1}{3} p_3$	$+ O$
" "	$y =$	$\frac{1}{3} p_3$	$+ O$	$- \frac{1}{3} p_3$

Let m be the co-efficient of elongation, *i. e.*, m is the intensity of a solid stress divided by the linear strain it produces. The value of m is numerically equal to the intensity of a solid stress, under whose action each edge of a unit cube would be elongated a unit, in case it could be so elongated, without passing the limits of elasticity. Hence, the elongation due to the solid stress $\frac{1}{3} p_1$ is $p_1 \div 3\, m$.

Also, let n be the co-efficient of shearing strain measured by the amount by which two parallel planes, at the distance of one unit apart, are displaced by the sliding effect of a shearing stress, *i. e.*, n is the intensity of a shearing stress divided by the shearing strain produced by it, and it is numerically equal to the intensity of the shearing stress which would cause a displacement of unity in two parallel planes one unit apart, provided the limits of elasticity were not passed in so doing. The values of m and n must be determined experimentally for any given material. It is evident that they serve to measure respectively the elasticity of volume, and the rigidity of the material.

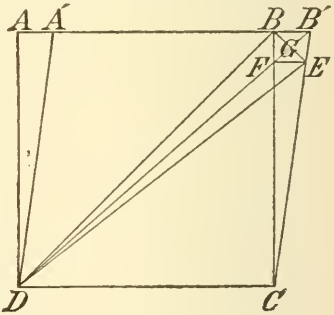


FIG. 2.

That we may obtain the relation between amount of shearing strain n and the amount of the elongation and contraction in the planes bisecting the angles between the planes of shear, let the unit cube $A\ B\ C\ D$ be infinitesimally distorted by a shearing stress of intensity p, acting on the parallel planes $A\ B$ and $C\ D$, accompanied by a shearing stress of equal intensity on the planes $A\ D$ and $B\ C$, such that they together are in equilibrium.

Let the shearing strain be $A\,A'$, then

$$\frac{A\,A'}{A\,D} = \frac{B\,B'}{A\,D} = \frac{p}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The shearing stress p is equivalent to a compression of intensity p along $A\,C$, and a tension of intensity, p, along $B\,D$. To find the elongation per unit in the diagonal $B\,D$, let $B'\,D$ cut $B\,C$ in F. Complete the infinitestimal square $B\,F\,E\,B'$. Now $A\,B$: $B\,B'$: $D\,B$: $F\,B'$ $(= 2\,G\,F)$, the total elongation is $\frac{1}{2}\,F\,B' = B'\,G = G\,F$. Hence, the elongation per unit is

$$\frac{G\,F}{D\,B} = \frac{\frac{1}{2}\,B\,B'}{A\,B} = \frac{p}{2n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The contraction occurring in $A\,C$ is of equal amount. Hence it appears geometrically that the elongation and the contraction per unit of length in the directions of the tension and the compression, which are equivalent to a shearing stress, is numerically one-half as great as the displacement of planes of shear one unit apart. On applying this conclusion to find the strain produced by the stresses in column 2 of the first table, which have an intensity of $\frac{1}{3}\,p_1$ along x and $-\frac{1}{3}\,p$ along y, it appears that they produce an elongation of $\frac{p_1}{6n}$ along x and $-\frac{p_1}{6n}$ along y. The stresses in column 3 act in a similar manner.

It thus appears that we may exhibit the elongations due to the component stresses into which p_1 has been separated, in the following tabular form:

		1		2		3
Strain along.....	$x =$	$\frac{p_1}{3m}$	$+$	$\frac{p_1}{6n}$	$+$	$\frac{p_1}{6n}$
" "	$y =$	$\frac{p_1}{3m}$	$-$	$\frac{p_1}{6n}$	$+$	0
" "	$z =$	$\frac{p_1}{3m}$	$+$	0	$-$	$\frac{p_1}{6n}$

Similarly the component strains into which p_2 has been separated produces strains tabulated as follows :

		4		5		6
Strain along.....	$y =$	$\frac{p_2}{3m}$	$+$	$\frac{p_2}{6n}$	$+$	$\frac{p_2}{6n}$
" "	$z =$	$\frac{p_2}{3\,m}$	$-$	$\frac{p_2}{6n}$	$+$	$\frac{p_2}{0}$
" "	$x =$	$\frac{p_2}{3m}$	$+$	0	$-$	$\frac{p_2}{6n}$

In like manner the components of p_3 cause the strains:

		7	8	9
Strain along.....	$z =$	$\frac{p_3}{3m}$ +	$\frac{p_3}{6n}$ +	$\frac{p_3}{6n}$
" "	$x =$	$\frac{p_3}{3m}$ −	$\frac{p_3}{6n}$ +	0
" "	$y =$	$\frac{p_3}{3m}$ +	0 −	$\frac{p_3}{6n}$

Denote the total elongation along x, y, z, due to the combined action of p_1, p_2, p_3 by l_1, l_2, l_3, respectively; then is the total elongation in either of these directions found, by taking the algebraic sum of the elongations due to each of the stresses p_1, p_2, p_3, as given in the foregoing tables; hence,

$$\left.\begin{aligned} l_1 &= \frac{1}{3}\left(\frac{1}{n}+\frac{1}{m}\right)p_1 - \frac{1}{3}\left(\frac{1}{2n}-\frac{1}{m}\right)(p_2+p_3) \\ l_2 &= \frac{1}{3}\left(\frac{1}{n}+\frac{1}{m}\right)p_2 - \frac{1}{3}\left(\frac{1}{2n}-\frac{1}{m}\right)(p_3+p_1) \\ l_3 &= \frac{1}{3}\left(\frac{1}{n}+\frac{1}{m}\right)p_3 - \frac{1}{3}\left(\frac{1}{2n}-\frac{1}{m}\right)(p_1+p_2) \end{aligned}\right\} \ldots\ldots (3)$$

These equations, expressing the elongations per unit of length x, y, z respectively, due to the action of p_1, p_2, p_3, are thus arranged in a form which exhibits separately the co-efficients of p_1, p_2, p_3. The first co-efficient shows how much effect a stress has in producing elongation in its own direction, and is often denoted by

$$\frac{1}{E} \therefore \frac{1}{3}\left(\frac{1}{n}+\frac{1}{m}\right) = \frac{1}{E} \ldots\ldots\ldots\ldots\ldots (4)$$

The second co-efficient shows how much effect a stress has in producing contraction in directions at right angles to itself, and it may be taken as some fraction k of the first co-efficient, thus:

$$\frac{1}{3}\left(\frac{1}{2n}-\frac{1}{m}\right) = \frac{k}{E} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

By (4) and (5), it is easy to express either of the four quantities m, n, k, E, in terms of two others; thus we find

$$\left.\begin{aligned} \frac{1}{m} &= \frac{3}{E} - \frac{1}{n} = \frac{1-2k}{E} = \frac{1-2k}{2n\,(1+k)} \\ \frac{1}{n} &= \frac{3}{E} - \frac{1}{m} = \frac{2\,(1+k)}{E} = \frac{2\,(1+k)}{m\,(1-2k)} \\ E &= \frac{3mn}{m+n} = m\,(1-2k) = 2n\,(1+k) \\ k &= \frac{m-2n}{m+n} = \frac{m-E}{2m} = \frac{E-2n}{2n} \end{aligned}\right\} \ldots\ldots (6)$$

By the help of (4) and (5), equations (3) may be written in the form:

$$\left.\begin{aligned} E\,l_1 &= p_1 - k\,(p_2 + p_3) \\ E\,l_2 &= p_2 - k\,(p_3 + p_1) \\ E\,l_3 &= p_3 - k\,(p_1 + p_2) \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Equations (3) can be arranged in various ways by expressing the constants in terms of either two of the quantities m, n, k, E. If we take for brevity $p_1 + p_2 + p_3 = q$, then (3) may, for example, be put in the following form:

$$\left.\begin{aligned} l_1 &= \frac{p_1}{2n} - \tfrac{1}{3}\left(\frac{1}{2n} - \frac{1}{m}\right) q \\ l_2 &= \frac{p^2}{2n} - \tfrac{1}{3}\left(\frac{1}{2n} - \frac{1}{m}\right) q \\ l_3 &= \frac{p_3}{2n} - \tfrac{1}{3}\left(\frac{1}{2n} - \frac{1}{m}\right) q \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (3a)$$

But equations (7) are of especial importance by the reason of the fact that the co-efficient E, which is known as "Young's Modulus of Elasticity," expresses the ratio of stress to strain in a piece subjected to direct tension or compression alone (*i. e.*, the lateral stresses vanish); while k is "Poisson's ratio," whose value may readily be seen to lie between the limiting values O and $\frac{1}{2}$; for, in case of perfect rigidity there is no lateral contraction, hence by definition $k = O$, while in case of perfect incompressibility, any longitudinal deformation must give rise to a total lateral deformation of one-half the amount in each of two directions, so that the total volume is unchanged, *i. e.*, $k = \frac{1}{2}$. But these constitute the two limiting cases between which all solids lie.

$$\therefore\ \tfrac{1}{2} > k > O.$$

Numberless experimental determinations of the value of E have been made within elastic limits, especially for iron and steel, so that its value is well known for the ordinary grades of material used in construction. There have been, however, but few determinations of the value of k for such materials. It has been frequently assumed by theorists that the value of k must be $\frac{1}{4}$ for all elastic solids. Experiment, however, does not show this to be the fact.

The following are the only trustworthy results of experiment known to me as to the substances named:

Wertheim	found	for	iron	.....	$k = 0.317$
Maxwell	"	"	"	.....	$k = 0.267$
Wertheim	"	"	mild steel	.....	$k = 0.310$
Okatow	"	"	"	"	$k = 0.304$
Schneebeli	"	"	"	"	$k = 0.306$
Kirchhoff	"	"	hard steel	.....	$k = 0.294$
Okatow	"	"	"	"	$k = 0.294$
Schneebeli	"	"	"	"	$k = 0.296$

The following table contains the ratios of m, n and E for several assumed values of k computed from (6), in which the number in the last column is the product of those in the two preceding columns:

k	$\frac{m}{E}$	$\frac{E}{n}$	$\frac{m}{n}$
0	1	2	2
$\frac{1}{4}$	2	2.5	5
$\frac{3}{10}$	2.5	2.6	6.5
$\frac{1}{3}$	3	$2\frac{2}{3}$	8
$\frac{1}{2}$	inf.	3	inf.

As before stated, it has been frequently assumed by theorists that k must be one-quarter for all elastic solids.

The set of linear equations (3) or (7) can be readily solved so as to express the values of p_1, p_2, p_3, each in terms of l_1, l_2, l_3. Instead of thus obtaining the stresses in terms of the strains, let us obtain them *de novo.*

A simple elongation along x can be regarded as composed of: 1st, a uniform dilatation of volume which elongates each edge of a unit cube parallel to each of the axes x, y, z, by the amount $\frac{1}{3} l_1$; 2d, a shearing strain producing an elongation of $+\frac{1}{3} l_1$, along x and of $-\frac{1}{3} l_1$, along y; 3d, a shearing strain producing an elongation of $+\frac{1}{3} l_1$, along x and of $-\frac{1}{3} l_1$, along z. Similarly, the elongation l_2 along y, and l_3 along z, can each be separated into three states of strain; in a manner precisely analogous to the separation of the stresses p_1, p_2, p_3, into component stresses in the first three tables given previously. If the word strain be substituted for stress, and l_1, l_2, l_3 be written for p_1, p_2, p_3, respectively, in those tables, we shall have a complete statement of the component states of strain. To produce these systems of strain there must be applied the states of stress exhibited in the following three tables, which are strictly analogous to the second set of three tables previously given, viz.:

		1	2	3
Stress along.....	$x =$	$\frac{1}{3} m l_1$	$+\frac{2}{3} n l_1$	$+\frac{2}{3} n l_1$
" "	$y =$	$\frac{1}{3} m l_1$	$-\frac{2}{3} n l_1$	$+ O$
" "	$z =$	$\frac{1}{3} m l_1$	$+ O$	$-\frac{2}{3} n l_1$
		4	5	6
Stress along.....	$y =$	$\frac{1}{3} m l_2$	$+\frac{2}{3} n l_2$	$+\frac{2}{3} n l_2$
" "	$z =$	$\frac{1}{3} m l_2$	$-\frac{2}{3} n l_2$	$+ O$
" "	$x =$	$\frac{1}{3} m l_2$	$+ O$	$-\frac{2}{3} n l_2$
		7	8	9
Stress along.....	$z =$	$\frac{1}{3} m l_3$	$+\frac{2}{3} n l_3$	$+\frac{2}{3} n l_3$
"	$x =$	$\frac{1}{3} m l_3$	$-\frac{2}{3} n l_3$	$+ O$
"	$y =$	$\frac{1}{3} m l_3$	$+ O$	$-\frac{2}{3} n l_3$

The total stresses p_1, p_2, p_3, along the axes x, y, z, respectively, are found by taking the algebraic sum of all the stress acting in each of these directions; hence,

$$\left.\begin{aligned} p_1 &= \tfrac{1}{3}(m+4n)\,l_1 + \tfrac{1}{3}(m-2n)\,(l_2+l_3) \\ p_2 &= \tfrac{1}{3}(m+4n)\,l_2 + \tfrac{1}{3}(m-2n)\,(l_3+l_1) \\ p_3 &= \tfrac{1}{3}(m+4n)\,l_3 + \tfrac{1}{3}(m-2n)\,(l_1+l_2) \end{aligned}\right\} \quad \ldots\ldots\ldots \quad (8)$$

If $l_1 + l_2 + l_3 = v$, then v is the amount of the cubic dilatation and equations (8) may be written:

$$\left.\begin{aligned} p_1 &= 2n\,l_1 + \tfrac{1}{3}(m-2n)\,v \\ p_2 &= 2n\,l_2 + \tfrac{1}{3}(m-2n)\,v \\ p_3 &= 2n\,l_3 + \tfrac{1}{3}(m-2n)\,v \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

If it is desired to write the contents of equation (8) in terms of E and k instead of m and n, these become by (6):

$$\left.\begin{aligned} p_1 &= E\,\frac{(1-k)\,l_1 + k\,(l_2+l_3)}{(1+k)\,(1-2k)} \\ p_2 &= E\,\frac{(1-k)\,l_2 + k\,(l_3+l_1)}{(1+k)\,(1-2k)} \\ p_3 &= E\,\frac{(1-k)\,l_3 + k\,(l_1+l_2)}{(1+k)\,(1-2k)} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots \quad (10)$$

Equations (9) may also be expressed in simple form in terms of k and n, thus:

$$\left.\begin{aligned} p_1 &= 2n\left(l_1 + \frac{k\,v}{1-2k}\right) \\ p_2 &= 2n\left(l_2 + \frac{k\,v}{1-2k}\right) \\ p_3 &= 2n\left(l_3 + \frac{k\,v}{1-2k}\right) \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

It appears from these equations that a stress in any direction produces deformations at right angles to it, and that deformation in any single direction, not accompanied by deformations in directions at right angles to it can only occur in general under the action of lateral stresses together with stress in the direction of the deformation. This statement is true whether the deformation is one which does or does not exceed the elastic limits of the material. In case it is beyond the elastic limits, the co-efficients E, k, m and n are not constant, as they are within elastic limits, and will have, consequently, different values for different states of strain. From this it follows that Professor Thurston's admirable experiments establish the existence of the effects mentioned, to which no definite numerical values can from the nature of the case be assigned.

F. Collingwood, M. Am. Soc. C. E.—Professor Johnson has mentioned the use of wire for bridge-work, this being especially noted as a material which has been strained far beyond its elastic limit, and which possesses

a maximum of strength with a minimum of stretch. In this connection it may not be amiss to mention some experiments made by Col. W. H. Paine, M. Am. Soc. C. E., when the matter of the specifications for the steel wire of the cables of the East River Bridge was under consideration. The exact details I cannot give, but they consisted in dropping a weight lengthwise of a suspended wire so as to strike an attachment at the lower end of the wire, and thus subject it to a heavy shock. It was found that with the same weight, the longer wires would resist the shock (even with a greater fall), while the shorter ones would be broken. The greater length in the longer wires gave a longer space in which to arrest the motion of the weight, and the shock was safely borne.

Now, when wire is used in suspension bridges, we have always a large number of wires side by side, and we can, with entire certainty, avail ourselves of the average strength of the material. In addition to this, the great length of the cables permits of a thoroughly elastic reaction, even with a very small amount of stretch remaining in the wire.

In ordinary bridge members, the case is quite different. We are dependent upon one, or at most a very few parts in one member. If these have been strained beyond the elastic limit, incipient rupture may have been developed, and the stresses, owing to deformation, may no longer be uniformly distributed.

D. J. Whittemore, Past President Am. Soc. C. E.—In testing iron the first lesson taught is, that the strength increases and ductility decreases within certain limits of stress, when the initial elastic limit is exceeded; and this being so it is quite reasonable to suppose that when the metal is afterward tested by tensile strains in any other direction, the same condition will be apparent.

The railway company with which I have been connected for many years, has increased its mileage by about one-half by the absorption of other lines having bridges designed for the loads of years ago. In renewing these bridges, after they had been subjected to modern loads, it was found that some of their truss rods had stretched several inches. In rebuilding I felt perfectly safe in using these rods again, but was careful to place them one or two panels ahead of their former position in the truss, or to places where the strains upon them would not exceed 10 000 pounds per square inch, and as yet have noted no failure.

Perhaps it is unwise or not prudent for me to say this to the young engineer, but the peculiarity mentioned gives me great faith in the reuse of iron that has been subjected to strains somewhat beyond the limit of elasticity, but not enough to very materially decrease the ductility.

George E. Thackray, M. Am. Soc. C. E.—I do not clearly understand from Professor Johnson what kind of material he proposes to use in structures. Does he advocate the use of material strained above or beyond the elastic limit ?

Prof. JOHNSON.—No.

Mr. THACKRAY.—Then I evidently misunderstood his statements.

Prof. JOHNSON.—I am not recommending anything. I think engineers might relieve their minds of that feeling which I have found exists, that when iron has been once strained beyond its elastic limit it is injured permanently. Not that we are going to strain all our iron beyond the limit and beyond what is due, not at all, but that we relieve ourselves of this anxiety in regard to the continued use of material which has been so strained.

GEORGE R. HARDY, M. Am. Soc. C. E.—If an experience with old iron is of any use, I can speak of a case where some bridges had been in use a number of years; even the wood had become weakened so that to get the old iron we had to take down the bridges, but in doing so as the rods were dropped to the ground below, most of them broke off as brittle as glass; I don't think we could take any advantage of that old iron.

Prof. JOHNSON.—That had probably not been strained beyond its elastic limit.

Mr. HARDY.—I think it had.

WILLIAM METCALF, M. Am. Soc. C. E.—There is one statement in the paper under discussion, against which I wish to make a respectful protest; it is, like many such statements, a general conclusion drawn from insufficient data. Coming as it does from so eminent an authority, it is calculated to mislead the younger members of the profession, if it be allowed to pass here without comment. The remark to which I object is, that "if a metal be subjected to a stress of any kind sufficient to produce permanent strain or set beyond its elastic limit, the ultimate strength will be increased sensibly in all directions about the line of action of the deforming stresses." The author calls attention to cold rolling, and wire drawing, as producing an increase of strength in the opposite direction.

In regard to wire drawing I cannot say, because I know of no experiments upon the strength of wire pulled transversely to its axis; we do know that a moderate amount of drawing or of cold rolling of bars does produce great increase of tensile strength, compressive strength, resistance to flexure, torsional strength and hardness; with decrease of density and a great decrease of ductility; we know from long experience that flat strands, cold rolled, are weakened dangerously across the line of rolling, and to avoid this weakening is one of the most serious problems of the cold roller. With all of this real and apparent increase of strength from drawing or cold rolling, we have great decrease of ductility, with great increase of brittleness. It seems as if one set of facts should be set over against the other carefully, and that the engineer should be left to draw his own conclusions.

Professor Thurston mentions the modulus of elasticity; I have a great respect for the modulus of elasticity, because since I worked it out as a

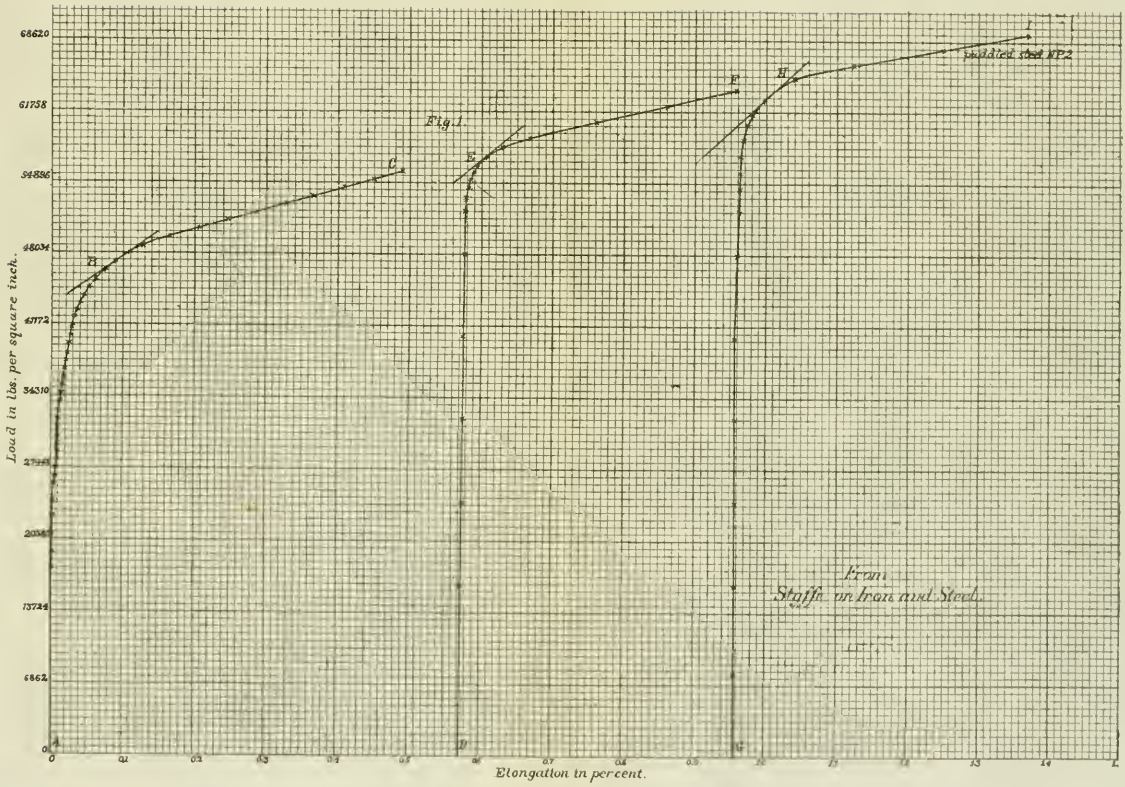
student in Troy, I never understood its application in formulas involving all manner of strains; for instance, a friend of mine had me provide him with spring bars, of steel mild, medium, and high; of each lot some were left as rolled, some were annealed, some hardened and tempered. They were sent to the Government testing machine at Watertown and tested, when it was found that they all had almost identically the same modulus of elasticity; therefore, to make a good spring you have only to get your bar of the right size by means of your formula which is based on the modulus of elasticity, and then the spring will be just the same whether the bar be mild or high, tempered, untempered, or even annealed. When the specifications for springs were issued finally, they required unusually high steel, well tempered. When asked what had become of the modulus, the reply was, "Oh, we found a great reserve of elastic strength in the high tempered steel."

One more point, a practical one, if you are using cold rolled, or cold drawn steel, it would be well to file a nick in an occasional piece and break it transversely; if the fracture shows a distinct dark or black core, reject the steel, it has been crushed in the rolling or drawing. This black is distinct, and should not be confused with the general dark cast or shade that is often noticed on mild and very good steel. The dark or black part produced by over rolling or over drawing, is so distinct from the true grayish blue of steel, that the shop name for it is the "black heart."

Professor Johnson.—You must excuse me for saying a word for my friend the modulus of elasticity. I simply want to say that we cannot compute any kind of distortion in metals without the aid of our friend, this modulus; you cannot compute the distortion of a spring without this modulus. A spring made of any kind of iron or mild steel will distort under a given load, and has exactly the same kind of springiness up to its elastic limit, as one made of spring steel. An iron spring is just as good as any other spring up to a certain point. I am rather inclined to think that the remarks of our esteemed Chairman on that subject were more worthy of an architect friend of mine in St. Louis, who refused to use steel beams in place of iron beams, because his hand-book told him that steel beams deflected one-fourth more than iron; the book also told him that the loads were one-fourth larger; if he had known about the modulus of elasticity he would have known that it was because of the greater loads upon the steel beams that deflected more, and that for equal sizes and loads they deflect equally, because their moduli of elasticity are the same.

Palmer C. Ricketts, M. Am. Soc. C. E.—The effect of the mechanical manipulation of cold metals (especially of those of the iron class), and of rest after such manipulation, on their elasticity and resistance to rupture, has long been known. To quote from Sandberg's translation, made in 1868, of Styffe's classic work on the Strength of Iron and Steel:

PLATE XVI.
TRANS. AM. SOC. CIV ENG'RS
VOL XXIV No 465.
RICKETTS ON
STRAINS IN METALS.



"INCREASE OF LIMIT OF ELASTICITY BY STRETCHING AND OTHER MECHANICAL MEANS.

"It is well known that the limit of elasticity in metals may be raised by cold-hammering, cold-rolling, wire drawing, or by any other manipulation which, acting in the cold, tends to change the relative position of the molecules of the metal. This method of increasing the elasticity is indeed often taken advantage of by workers in metal. We shall afterward show that the absolute strength may also be augmented by similar mechanical treatment, but that the extensibility is at the same time diminished.

"In order to show in what proportion the limit of elasticity is raised by tension, let us refer to the plate (reproduced in Plate XVI of this article), where the curve *A B C* represents the elongation which a sample bar has obtained by loads amounting to 55 925 pounds on the square inch; whilst the curves *D E F* and *G H I* show the elongations produced when the same bar, after having been stretched ten times by a force of 1 029 pounds per square inch, was again tested with a smaller weight, which was gradually increased to 63 816 pounds per square inch; and, finally, for the third time, was submitted to the action of the same force as at the commencement. In these curves all the points determined by observation are marked with a cross. In the curve *A B C* the limit of elasticity is placed, according to the first experiment, at 47 004 pounds; according to the second at 57 279 pounds; and to the third at 63 160 pounds. The limit was thus raised by tension 16 126 pounds.

"The same plate also shows that the upper parts, *B C*, *E F*, and *H I* lie in the continuation of the direction of each other. By experiments with several other sample bars of iron and steel, the author is persuaded that the same thing always occurs when a bar is stretched beyond its limit of elasticity, and then submitted to fresh tension, provided that the new series of experiments closely follow the previous ones, and that the temperature during the whole time has not varied to any great extent. If, on the contrary, the bar be allowed to rest a while before the experiments are renewed, and especially if it be gently heated (for example, to 300 degrees Fahr.) the limit of elasticity is often found to be much higher than might have been expected, in consequence of the tension to which it was previously submitted."

The distinguished author of the paper under consideration, who has done so much to increase our knowledge of the physical properties of metals, also showed independently in 1873, that a similar increase resulted when these metals were subjected to torsional strains. The experiments of Gilmore showing the effect of torsion, and of Parker showing that of cold bending on tensile resistance, are also noticeable.

Although these and similar facts have long shown the possibility of subjecting structural material to stresses beyond the primitive elastic

limit, without imminent danger to the structure (in fact, cases in which the end tension members of old Howe truss bridges have doubtless been often so stressed, have probably come within the experience of most bridge engineers); and although advantage has often been taken of the knowledge of the effect of cold working, to produce material with special qualities suitable for the purpose for which it was intended (as, for instance, wires for the cables of suspension bridges), the decrease in the percentage of elongation and in the reduction of area, and the change beyond this point in the character of the metals of the kind and of the forms and sizes at present generally used, render it extremely doubtful whether these properties, developed by mechanical manipulation of cold metal beyond the initial elastic limit, can properly be taken advantage of in structural design. This is especially true when it is considered, that known metallurgical processes enable material to be made, with initial properties approximating those shown to exist in the ordinary material in use—caused by straining and rest after the initial limit has been passed—probably of more homogeneousness, and quite certainly more economically than it can be by mechanical manipulation when cold.

The comparatively small change in the modulus of elasticity produced by straining and rest beyond the elastic limit, also affects the question.

Whatever character of metallic material may be fixed upon as proper and allowable for structural uses (opinions upon this question differing, of course, to a certain extent, and also as to whether the properties of the material be fixed by hot or cold mechanical manipulation); there can be no question of the propriety of keeping the maximum induced stress in all cases below the known resulting elastic limit, which may properly be called primitive, and very considerably below it, where often suddenly recurring, as long as distortion is considered to be objectionable. That is, no engineer would be supported "in designing structures in which the stresses approach, or may exceed separately or in combination, the normal primitive elastic limit of his material."

In fact, possible inequalities of material and workmanship, will always render a considerable margin between the induced stress and the elastic limit of the parts considered, advisable and necessary, even where this stress is static and can be quite closely deduced.

In this connection Table No. 1, taken from the report of tests made at Watertown Arsenal, on wrought-iron bars of considerable size, during the year ending June 30th, 1882, is interesting.* The change in the character of the fractures from fibrous cross-sections to those which are largely granular, is especially noticeable; and the well-known effect of heating to redness and annealing after stressing beyond the elastic limit, and of heating to a moderate temperature and cooling, also appears.

* Forty-seventh Congress; 2d Session; Senate; Ex. Doc. No. 1.

TABLE No. 1.

TABULATIONS OF TENSILE STRENGTH OF WROUGHT-IRON BARS, SHOWING ORIGINAL STRENGTH AND STRENGTH AFTER THE BARS HAD RESTED; ALSO STRENGTH AFTER ANNEALING.

No. of Test.	Condition of bar when tested.	Size of bar when tested.			Strains on original section.		Strains on reduced section.		Uniform elongation from original length.	Contraction of area from original section.	Appearance of Fracture.	Remarks.
		Width.	Thick.	Sectional area.	Elastic limit.	Ultimate strength.	Elastic limit.	Ultimate strength.				
		In.	In.	Sq. in.	Lbs. pr. sq. inch.	Lbs pr. sq. inch.	Lbs. pr. sq inch.	Lbs. pr. sq inch.	Per ct.	Per ct.		
993	Original	3.05	1.00	3.05	29 500	51 150	.....	.....	21	31.5	Fine fibrous.	
	Rested four months since original test	....	....	....	.....	60 000	.....	.....	24	....	Fibrous, 90 per cent.; granular, 10 per cent.	
994	Original	3.05	1.00	3.05	28 500	51 110	.....	.....	21	36.1	Fine fibrous.	
	Rested four and two-third months	....	....	...	53 440	61 960	.....	.....	25	33.8	Fibrous, 92 per cent.; granular, 8 per cent.	
981	Original	3.05	1.01	3.08	28 000	50 390	.....	.....	14	35.1	Fibrous.	
	Rested five months	....	....	....	.....	60 390	.....	.....	20	21.8	Granular, 70 per cent.; fibrous, 30 per cent.	
973	Original	5.05	1.28	6.46	27 500	50 500	.....	.....	13	24.2	Fibrous, 95 per cent.; granular, 5 per cent.	
	Rested eight months	....	....	....	56 500	58 980	.....	.....	18	17.	Fibrous, 30 per cent.; granular, 70 per cent.	
	Heated cherry red and cooled in open air.	4.75	1.17	5.56	21 670	{36 220 / 41 640}	26 080	{42 090 / 48 380}	33	....	Fibrous	Broke at end of annealed section.
774	Original	3.03	1.01	3.06	29 500	53 630	.....	.....	16	36	Fibrous, 92 per cent.; granular, 8 per cent.	
384	Rested ten months	2.84	0.94	2.67	53 920	63 130	61 800	72 360	23	21.9	Granular.	
385	Heated dull red and cooled in open air	2.80	0.92	2.58	22 800	41 240	27 130	48 910	32	34.0	Dull fibrous.	
777	Original	3.03	1.01	3.06	29 000	53 560	.....	.....	15	37.9	Fibrous.	
386	Rested ten months	2.87	0.95	2.73	53 920	63 070	60 440	70 696	19	19.6	Fibrous, 10 per cent.; granular, 90 per cent.	
387	Heated to 370 degrees and cooled in open air.	2.83	0.92	....	57 520	57 520	67 700	67 706	19	34.6	Fibrous, 60 per cent.; granular, 40 per cent.	
	Rested fifteen days after third test	....	....	....	.....	62 420	.....	.....	....	....	Fibrous, 60 per cent.; granular, 40 per cent.	
971	Original	3.03	1.01	3.06	32 500	53 500	.....	.....	16	27.5	Fibrous.	
388	Rested nine months	2.84	0.94	2.67	55 880	63 360	64 040	72 620	21	19.9	Fibrous, 30 per cent.; granular, 70 per cent.	
389	Rested nine months	2.84	0.92	2.61	.....	66 010	.....	77 400	21	19.9	Fine granular.	

The experiments made by Mr. Bissell are very ingenious and instructive. In the line of his Series A, and to show perhaps a little more strikingly the effect on tensile resistance of stressing metal beyond the elastic limit, the writer had three bars of machinery steel and two bars of bronze of unknown composition, all about ¾ inch in diameter and about 22 inches long, turned down as shown in the specimen lettered *X* in Plate XVII, that is, leaving 4 inches for gripping at one end. Three spaces, each 2 inches long, separated by distances of 1 inch, were turned down to about ½ inch in diameter, and the remaining 10 inches of the bar were left of the original diameter. These bars were then tested by tension until a decided set was obtained in each. Leaving the 4 inches for gripping at one end as before, the specimens were then turned down for a length of 14 inches to uniform diameters of somewhat less than ½ inch, which left about 4 inches for gripping at the other end. They were then again subjected to tension until decided necking resulted, and in this condition are shown at *A*, *B*, *C*, *D* and *E*, in Plate XVII. The specimens were elongated in this test until the distance between the shoulders, in the steel pieces, was about 15½ inches and in the bronze pieces about 14¾ inches.

In all cases the neck formed in the 6 inches near one end, which had not originally been turned down and at distances from the end of the piece given in Table No. 2.

In all of the steel pieces the effect of the strain due to the first test is strikingly shown; those portions which were turned down at first—three spaces, each 2 inches long—remained of the same, or nearly the same, diameter after the final test (see columns II, IV and VI of Table No. 2), whilst the two portions between them, each 1 inch long, and the portion 6 inches long near one end, which were not turned down until after the first test, were reduced decidedly in cross-section (see columns I, III and V of Table No. 2), thus giving the specimens a wavy appearance with three alternating nodes and depressions, apparent at a glance. These show in the photograph, and may be seen in Plate XVII, reproduced from it.

In Table No. 2 the various diameters, measured to thousandths of an inch, before and after the tests, show this clearly. As may be seen from Plate XVII, columns II, IV and VI of this table refer to the parts 2 inches long turned down at first, and columns I, III and V to the parts not turned down until after the pieces had once been subjected to tension.

This wavy appearance, as was to be expected, is not so apparent in the bronze specimens, though it may be seen in the one marked *E*, and it is decidedly shown to exist, though in a lesser degree than in the steel pieces, by reference to Table No. 2.

The necking of the bronze pieces at the points shown was somewhat unexpected, from the fact that the reduction of area in each specimen

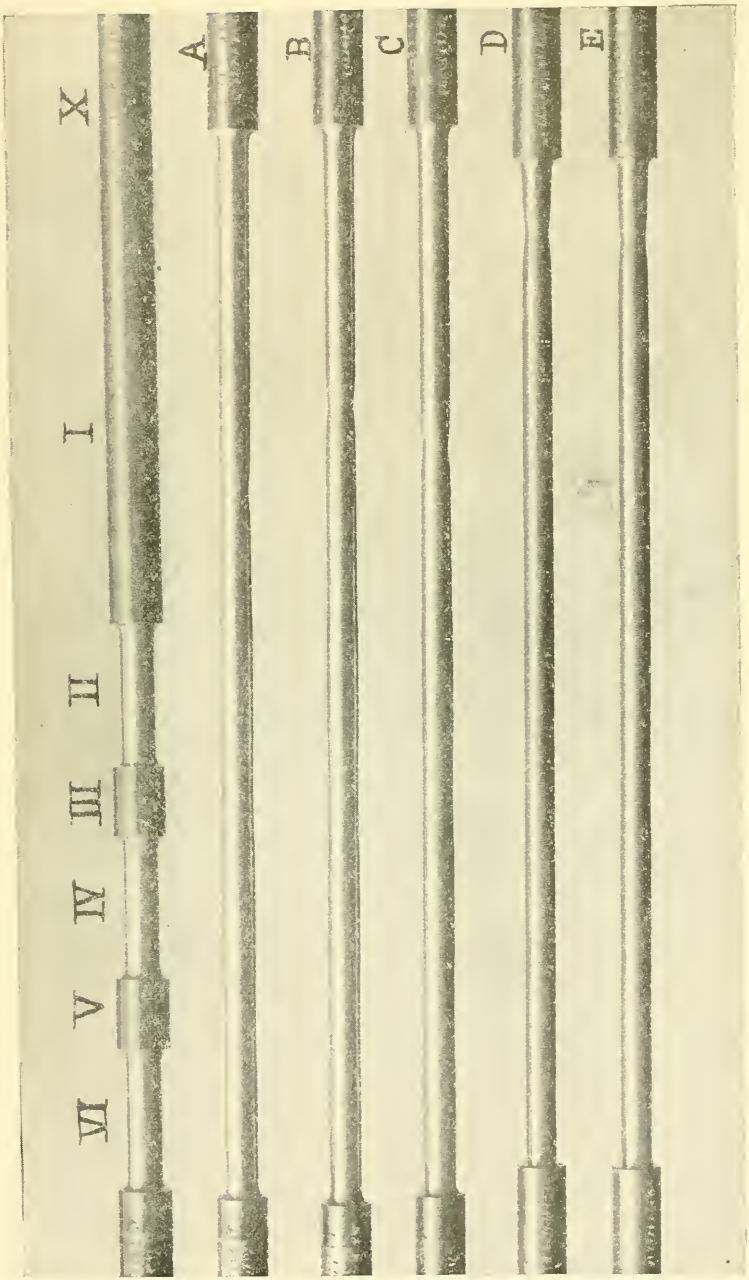

VI
V
IV
III
II
I
X
A
B
C
D
E

TABLE No. 2.

Mark.	Material.	When diameters were measured.	Diameters in Inches at Points Numbered.							Remarks.
			I.	II.	III.	IV.	V.	VI.	Neck.	
A	Machinery—steel.....	Before testing.....	0.765	0.510	0.765	0.510	0.765	0.510		
		After first test.....	0.765	0.501	0.765	0.501	0.765	0.501		
		Turned 14 inches long...	0.494	0.494	0.494	0.494	0.494	0.494		
		After second test.....	*0.468	0.493	0.463	0.493	0.468	0.489	0.402	Neck 9¼ inches from end.
B	Machinery—steel.....	Before testing.....	0.765	0.509	0.765	0.509	0.765	0.511		
		After first test.....	0.765	0.500	0.765	0.499	0.765	0.501		
		Turned 14 inches long...	0.497	0.497	0.496	0.496	0.495	0.495		
		After second test.....	*0.463	0.496	0.465	0.492	0.471	0.488	0.389	Neck 8 inches from end.
C	Machinery—steel.....	Before testing.....	0.765	0.509	0.765	0.509	0.765	0.509		
		After first test.....	0.765	0.498	0.765	0.498	0.765	0.498		
		Turned 14 inches long...	0.492	0.492	0.490	0.490	0.492	0.492		
		After second test.....	*0.462	0.490	0.461	0.490	0.466	0.486	0.385	Neck 8½ inches from end.
D	Bronze.....	Before testing.....	0.748	0.508	0.748	0.509	0.748	0.508		
		After first test.....	0.748	0.475	0.748	0.499	0.748	0.499		
		Turned 14 inches long...	0.458	0.458	0.458	0.458	0.458	0.458		
		After second test.....	*0.450	0.458	0.452	0.458	0.457	0.458	0.364	Neck 5 inches from end.
E	Bronze.....	Before testing.....	0.748	0.509	0.748	0.509	0.748	0.509		
		After first test.....	0.748	0.499	0.748	0.494	0.748	0.474		
		Turned 14 inches long...	0.471	0.471	0.471	0.471	0.471	0.471		
		After second test.....	*0.468	0.471	0.451	0.471	0.464	0.471	0.379	Neck 5¼ inches from end.

* Measured far from the neck; this portion was, of course, conical near the neck.

during the first test, was not uniform in the turned down portions, but was decidedly greater in one of these portions of each piece than in the others, thus showing weakness at these points. This may be seen by referring to column II, bar *D*, and column VI, bar *E*. Both necks formed, however, in portions not turned down until after the first test. It should be stated that an interval of about five days elapsed between the first and second tests of all the specimens.

R. H. Thurston (closing the discussion).—Taking up the points made by the speakers in the order of their presentation.—I agree with Professor Johnson in his remark that the facts to which he refers are not to-day new; they were presented by me to the Society as early as 1873-74, if I remember aright, and will be found in the *Transactions* of about that time (1). I think, however, the particular facts illustrated by the experiments here recited in the paper are novel, except so far as given by me elsewhere. A report made by me to the American Iron Works, many years ago, contains an account of the most extensive, and, I think the only very extended investigation of the action of cold-working, ever made. That firm will probably be able to supply copies to members who desire them. An abstract of the work will be found, perhaps amply sufficient for present purposes, in my "Materials of Engineering," Vol. II, in the chapter on "Conditions Modifying Strength," as well as a development of the other points now presented by the first speaker (2). I see his experiments date 1878; mine go back far beyond that time. The fact that strain does not necessarily injure materials of construction was shown by me about the same time, in papers read before this Society, of which that on the permanent registry of the strain by elevation of the elastic limit, is perhaps the most interesting in this connection (3). In one case I suggested the practicability of first testing a bridge-bar to its elastic limit, to insure that it is strong and safe, and then putting it in the bridge—a perfectly feasible thing (4).

Mr. Skinner thinks this impracticable. I think it will be found perfectly practicable with the testing machines now becoming common. The testing of the member within the elastic limit is perfectly safe, and yet gives a reliable gauge of the value of the piece. Once the character of the material is revealed by an investigation which enables the engineer to show the early part of the curve, as in the diagrams of Mr. Ricketts, the rest becomes sufficiently well established—knowing as we do the nature of the composition of the metal—and we can then, if this first part is satisfactory, put the piece in its place with perfect safety and confidence. The extensive use of cold-rolled iron and steel is ample evidence that this is the fact in many directions in the arts. There are, it is true, many cases in which the effort demanded to carry the member up to its elastic limit is too great for ordinary testing-machines; but we have the Watertown machine—once in a while, at any rate—and there are a number of 200 000 and 300 000 pound machines in existence, to say nothing

of the million-pound machine at Athens. I have just started a 300 000-pound machine for Sibley College; we have already a number of others of smaller sizes, and shall have more in the course of the year; so that it may safely be assumed that between the builders and the technical schools we shall be able, in time, to do even this sort of work.

I think Professor Johnson is right in his views relative to this matter.

Professor Eddy's discussion is very interesting; and I think we owe him hearty thanks for thus summarizing the work done to date by the builders of the "theory," which is better called, I think, the true philosophy of the subject. It has always been to me a matter of much surprise that engineering authorities have so closely followed the mathematicians in developing simply a theory of elasticity. While it is true that, so long as the member, in any structure, is doing only its regular and proposed work, its action is completely covered by such theory; yet it is also true that, the instant a critical condition arrives, through accident or the effect of overloading due to carelessness or decay of strength with age and corrosion, the theory of elasticity no longer applies, and that of permanent strain, as well as stress, must be resorted to. I have called attention to this fact in my own work, and, on referring to my Materials, second volume, where the expressions for resistances to transverse and torsional strain are deduced, it will be seen that I show there that the apparent discrepancy sometimes asserted to exist between the theoretical and actual behavior of metal may be fully accounted for by these facts (5). The behavior of a member beyond its elastic limit becomes a matter of serious importance the instant it is overstrained.

Mr. Collingwood's remarks have, in this relation, an important significance. It might also have been remarked that the self-regulating and self-adjusting power of the metal, when under the action of forces producing progressive distortion, is a very interesting and valuable property. Thus a wire or a rod under tension, if first pulled beyond its momentary elastic limit, then allowed to rest, then pulled again, then resting, and so on, will finally be found to have produced, by an automatic action, if I may use that term, a very uniform resisting power, from end to end, irrespective of minute ordinary variations of original elastic and ultimate resistance. I am fully in agreement with Mr. Whittemore as to the re-use of strained metals, and think it will often be found that they are thus made all the more valuable and safe for certain purposes; as where stiffness and rigidity, and the retention of their original dimensions and form is the most essential matter. If he put his old bridge-rods where, in case of overloading, they shall not be those on which most extension must occur, he will be sure to increase the safety of his bridge by their use (6).

The cases mentioned by Mr. Hardy are not uncommon; but I think it will always be found that the defects are not such as bear upon the question here under discussion. Some compositions of both iron and

steel will exhibit that brittleness and progressive crystallization—especially, I think, when containing much phosphorus—which change is due to the repeated stretching of the material by overload and its attempted return to its primitive magnitude; but a wide range of stretch and recoil is, in this case destructive (7). It is only the best qualities, as we find by experience as well as by experimental investigation, that are fitted for cold-treatment. The American Iron Works always get a special quality for cold-rolling; the makers of cold-pressed nuts do the same, and I think the engineer should be as careful in the selection of his materials for bridge-work, in which case he may feel safe with rods previously loaded to the elastic limit.

Mr. Metcalf's criticism has, perhaps, a basis in my own inattention to the collateral facts; but I think the paper, nevertheless, states what it does state with perfect accuracy. The brooming and splitting of bars, to which he refers, is due, not to the stress carried up to and beyond the elastic limit, but even farther, until the metal is actually disrupted. Of course, that case was not contemplated in the paper, or in the work which it described; it does not seem to me necessary that it should have gone outside its title to take up obviously irrelevant cases of that sort. It is perfectly true (as is, I had assumed, too well known to require the introduction of foot-notes on the subject) that decreased ductility always accompanies the elevation of the elastic limit by strain. Where the piece is to be subjected to shocks and blows, this becomes a matter for serious consideration; and the fact should always be recognized and kept in mind. The test which he gives us for injured steel is one which we are all, I am sure, glad to know. I imagine that it comes from the minute separations of particle from particle, due to overstrain. I think that Professor Johnson puts the "Modulus" business in the right light.

Professor Ricketts's contribution of facts to the discussion is most welcome. The older writers, as Morin (long before Sandberg), and also Hodgkinson and others, were well aware of the fact that strain would raise the primitive elastic limit. I think, however, that the first experiment showing precisely how strain, irregularly applied, would produce a peculiar variation of the normal series of elastic limits, as I have called them, was reported by me to this Society in the fall of 1873, as the result of first experiments with my "autographic testing machine." Many other similar investigations followed and were later reported to the Society, in many of which that self-registering system was made useful in revealing, beyond dispute, this singular phenomenon, of which I think I was the discoverer (8). The list which follows, on papers of this character, all of which are in the *Transactions* of the American Society of Civil Engineers, will afford, I think, many interesting facts in this connection.

The action of the bronze is a new discovery, I think; though in my reports to the United States Iron and Steel Board, there will be found

the intimation that such a phenomenon might be now and then observed with certain compositions. This experiment, as reported in the paper, settles that matter. But I am inclined to think that the field is still open for further exploration.

1.—*Transactions* Am. Soc. C. E., 1873: Elevation of the Elastic Limit by Strain. *Transactions*, Vol. II., p. 290. *Transactions*, February 4th, 1874: Strength, etc., of Materials of Machine Construction.

2.—Materials of Engineering, Vol. II.; especially articles 466, 600, 608, 610. *Transactions*, Am. Soc. C. E., March, 1878.

3.—Same; articles 347, 549.

4.—*Transactions*, 1874, as above; Materials, Vol. II., article 299. *Transactions*, Am. Soc. C. E., No. 191, 1880.

5.—See especially articles 261, 262, 263 and 277.

6.—See articles 295, 296, 298, and especially 299. *Transactions*, Am. Soc. C. E., March, 1878.

7.—See article 292 (Crystallization) for some curious facts.

8.—See articles 297, 298, especially figure 137; *Transactions*, Am. Soc. C. E., 1876, 1877; also Metallurgical Review, 1877; Mechanical Treatment of Metals, R. H. T.; and Reports of United States Board appointed to test Iron, Steel and other Metals, 1878.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

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466.

Vol. XXIV.—March, 1891.

DISTRICT STEAM SYSTEMS.

By CHARLES E. EMERY, Ph. D., M. Am. Soc. C. E.

Since presenting at a meeting of the Society, lantern views showing the principal details of the plant of the New York Steam Company, portions only of which have appeared in the *Transactions*, it has been thought desirable to present for publication, at this time, a general statement of the present condition of the plant after a practical test of over eight years; and in connection therewith, to point out lessons to be drawn from this installation, and forecast the probable future of the business.

The writer first examined the subject in the winter of 1879–80, and the Company's organization and plant were so far completed, that work was in progress during part of 1881. Steam was first turned on for use in the spring of 1882, and the supply was extended from section to section as rapidly as the pipes were laid.

In 1886 the plant, though not finished as designed, was in thorough working order in all engineering, mechanical and business details, and the construction of both the up-town and down-town stations had advanced as far as possible under the then existing conditions. The

writer, then manager and engineer of the Company, endeavored to effect some reorganization and retire to a consulting position, but only the preliminary steps were taken and the responsibility remained as before until October, 1887, since which he has had no connection with the work. At that time the basement and three stories of the down-town building, known as "Station B," on Greenwich street, between Cortlandt and Dey streets, had been completed, and forty-eight Babcock & Wilcox boilers, of 250 horse-power each, placed therein, in three tiers; a total of 12 000 horse-power. The fourth story, which was designed to finally receive boilers, had also been partially carried up and roofed over temporarily for the storage of coal, which, it will be recollected, is distributed to the boilers, from the bunkers above, through chutes in front of alternate central supporting columns, the ashes passing to the basement through similar chutes opposite the intermediate columns. A general idea of the building and dimensions of chimney may be obtained from the paper of the writer, Vol. XIV, *Transactions*, page 180. Before 1887, however, another chimney had been added on the north side, shown in Figs. 1, 2, 3 and 4, Plate XVIII. It was made of octagonal section, and covered only one-half the base provided for a second chimney like the first. It started at an elevation of about 130 feet above high water and terminated, like the other, at an elevation of 220 feet above high water, the size being such that another similar chimney could be placed alongside it on the rectangular base. The cap was made of wrought-iron plates with internal iron ribs.

The pipes from the down-town station of the company extend through nearly 5½ miles of streets, and from the up-town station through nearly 2⅓ miles. A small portion of the latter have been put in since 1887, and more boilers have been added in the up-town station to meet the increasing demand. Four new boilers have also been placed in the down-town station, requiring that one-quarter of the fourth floor of the building be arranged to receive them. The system necessarily adopted originally, of temporarily roofing with wood, has, however, been continued.

A general idea of the territory reached by the steam mains could be obtained from a map, but the magnitude of the work can best be judged from a detailed statement of the size of steam mains laid in particular streets in the down-town district, all of which, with the exception of some unprofitable dead ends, are still in operation at a pressure of

from 80 to 90 pounds. The pipes are of wrought-iron, the sizes stated referring to inside diameters for 10-inch, 8-inch and all smaller pipes, and to outside diameters, as is common with boiler tubes, for the 11-inch, 13-inch, 15-inch and 16-inch sizes, the inside diameters of the latter being practically ½-inch less than diameters given.

The first main laid from the Greenwich street station was 11 inches in diameter, and extended northerly through Greenwich to Warren street, with 6-inch branches in Fulton and Vesey streets, extending to Church, and the former connecting to Broadway through a 15-inch line, intended eventually as a supply pipe by another route. The 6-inch branch in Fulton street, has recently been enlarged to accomplish the purpose. There was also an 11-inch line in Barclay street, a 6-inch line in Park place and in Warren street, and an 8-inch line in Murray street, extending to Broadway. Another steam main 15 inches diameter, extended from the station, up Cortlandt street to a cross in Broadway, from which pipes of the same size were run up and down Broadway and in Maiden lane. From Dey street north to Reade street, a double line of pipe 15 inches in diameter was laid, with the intention of eventually connecting the same with the station through Dey street. The Broadway mains north, connected with pipes on the west side in the streets already mentioned, and there was also an 8-inch pipe run on Reade street from Broadway to West Broadway, a branch from which extended along the latter street a short distance. On the east side, a 13-inch pipe in Mail street was connected with an 11-inch in Park row, which extended a short distance down Spruce and Beekman streets. The latter pipe connected with a 6-inch pipe through Theater Alley, which, through Ann street, connected again with Broadway, opposite Vesey street. The 15-inch pipe on Fulton street extended easterly across Broadway to Nassau street, and was continued by an 11-inch pipe to William street. The Maiden lane pipe was 15 inches diameter to William street, and was continued easterly by 8 and 6-inch pipes nearly to Pearl street. South of Cortlandt street a 15-inch pipe ran down Broadway and Whitehall street to the Produce Exchange, with a branch through Beaver to New streets and from thence to Exchange place. There was also a 15-inch line in Wall street, from Broadway to William, extended by a 13-inch pipe to Pearl, and by a 6-inch to Water street. From Wall street an 11-inch branch pipe was extended down Broad street nearly to Exchange place. A 13-inch pipe connected the Wall

PLATE XVIII.
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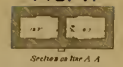
FIG. 3.

Section on line B B

FIG. 4.



Section on line A A

FIG. 1.

FIG. 2.

FIG. 6.

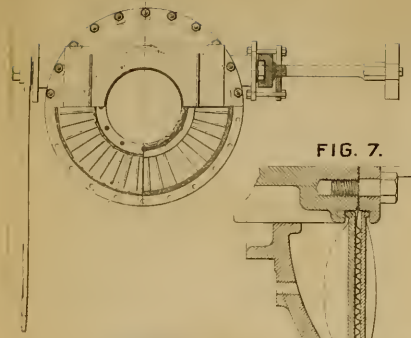


FIG. 7.

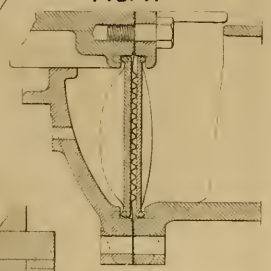


FIG. 5.

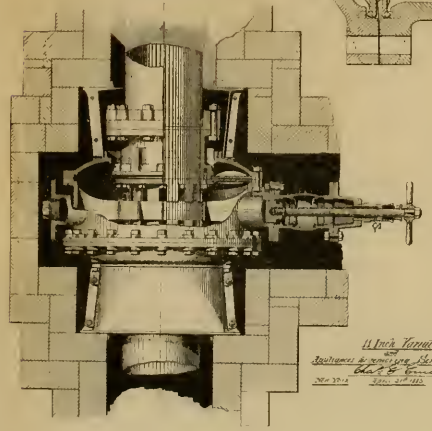


FIG. 8.

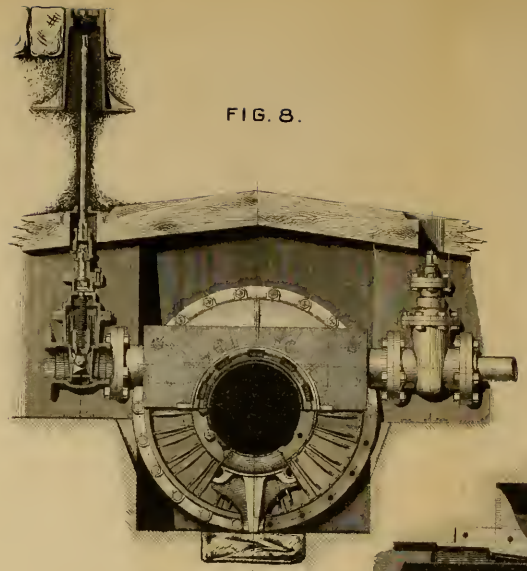
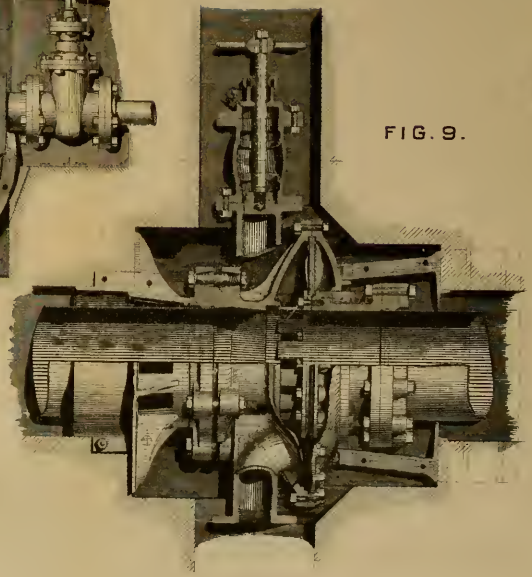


FIG. 9.



and Maiden lane pipes, through William street, from which last pipe a 6-inch connection ran through Liberty street, from William street to Broadway. On the west side, a 16-inch main runs south on Greenwich street, from the station to Liberty street, where it connects with Broadway through an 8-inch pipe; and the Greenwich street line is continued with 15-inch pipe to Rector, and up the latter street to Broadway. There are also a number of branches of comparatively small pipe which act as mains, and some connections through buildings, and some large buildings have service pipes, all of which are not now in use, of sufficient size to be called mains; there being one to the Produce Exchange 11 inches diameter, one to the Mills Building 8 inches in diameter, another to the Mutual Life Building of the same size, one of 6 inches to the Telephone Building, one of the same size to the Western Union Telegraph Building, another to the old *World* Building, one of 8 inches to the *Tribune* Building, one of 10 inches from Mail street to the New York Court House and Post Office Building, and another of 6 inches from Broadway to the same building. The New York City Hall is supplied through a pipe running under the greensward of the Park. In connection with these pipes, return mains were laid the whole distance. They were 8 and 6 inches in diameter near the boiler house, and reduced to 4 and even 2½ inches in diameter near the ends of the lines.

The up-town station was built in 58th street, near Madison avenue. The building is ornamentally designed with terra cotta trimmings, so as to be architecturally in keeping with the dwellings in the same block; the writer being assisted in the architectural treatment by Mr. W. C. Haslett, architect. The building is on a lot which had been filled in over a former muddy stream, but as it was leased ground, a light building of two stories and basement only was designed, with boilers on main floor and coal storage on the upper floor. The walls between the boilers were supported on arches in the basement, and were carried up to support the coal bins; and there being about 8 feet of old compact filling left below the foundation, no piles were used under the main part of the structure. The chimney, however, was set on a pile foundation, an opening for the same being cut through to the mud. Great difficulty was encountered in driving the piles, on account of broken stone which had been used for filling, in connection with earth, when the streets were graded. The building has stood well, only cracking at one

corner next to an adjoining vacant lot, which was probably filled at a later date. Considerable study was required to utilize the space available. The west end is an office building, with an arch at the side for the entrance of the coal carts. It was at first intended to back the carts in, but to conciliate the neighborhood the plan was changed, one boiler omitted, the steam pipes crooked more than was expected, and the carts now drive in beyond the center of the building, when two trap doors are raised behind, and the coal is dumped through the floor into a loading bin, and from this into a car below, which can be run on an elevator at the side within the lines of the office building. From the elevator it is run on a transfer car on the upper floor, and transferred to rails running over the bins at either side. Similar longitudinal and transfer rail lines are arranged in the basement, so the ashes may be drawn into cars from pans under the boilers, carried up on the elevator and dumped in a bin over the driveway, where they can be rapidly loaded in the carts. The building is designed to contain twelve boilers of 200 to 250 horse-power each, of which six have been put in place. The flues from the boilers are carried around against the walls in the basement. Two 10-inch pipes are laid from this station to Madison avenue. The distribution is on Madison avenue from 54th to 68th streets, with a number of branches, mostly on the west side toward Fifth avenue. There is also a main on Fifth avenue from 58th to 53d street, with some connections in cross streets between Madison and Fifth avenues. This plant was designed like the downtown one to carry 80 pounds of steam and to run summer and winter, but the pressure has in general been kept lower, and steam supplied only during the winter. Recently, Mr. F. H. Prentice, the present Manager and Engineer, has been carrying high-pressure on some of the boilers and supplying electric lighting engines, then using the exhaust at 30 to 40 pounds pressure to partially supply the steam mains. The writer started at one time to convey exhaust steam from an electric lighting plant through street mains for heating, and such a plan was actually carried out soon after in another city, though not at the high pressure Mr. Prentice is now using.

At this date the steam mains are, with the exception of some leaky joints to be referred to hereafter, in apparently as good condition as when laid. A steam pressure of upward of 80 pounds is maintained upon them continuously, night and day. The return main system has proved a failure,

on account of external corrosion, though the pipes were in every way similar to the steam pipes as respects material and fittings, were laid in the same trench, and protected and connected in the same way. Both the steam and return mains were covered with asphalt varnish applied hot with a brush as the pipes were laid; the pipes, however, were not heated. The varnish on the steam pipes still remains; that on the return pipes has been forced off in large patches by ordinary rust. The corrosive action, when once started, was apparently locally cumulative; crater-shaped cavities being formed, which, in due time, penetrated the pipe, allowing the water to escape. This action required several years for its full development. When the writer was connected with the company, the only trouble had been with the smaller return connections, and the action was attributed to the fact that they were alternately cold and hot, under which conditions iron readily rusts in all locations, but particularly when in contact with a porous material which prevents the moisture from evaporating freely. There had been a single case of a small hole in a larger return pipe and a similar one in a steam pipe, which were attributed to cinder rolled in. Later, however, the general action took place and was immediately followed by similar phenomena in the return pipes uptown, which were not laid until several years after. Without going into details, the conclusion reached is, that the carbonic acid in the atmosphere and soil, the principal active element in inducing corrosion, has a particular active effect at or about a temperature of 210 degrees to 220 degrees, corresponding to that in the return mains; that at lower temperatures the action is less violent, and at higher temperatures, like those of the steam mains, the moisture is at once repelled, and any water touching them at once assumes the spheroidal state, so that absolutely no corrosion takes place. The fact that iron corrodes with great rapidity at or about the temperature of boiling water, is believed to be unknown to the majority of engineers. The writer had previously heard of the corrosion of return pipes, the same as he had of boilers, but never in any connection which could not apparently be explained by leaky joints, and alternate heating and cooling of the surfaces. It is doubtless true that in individual cases it was known that pipes in a heating system had corroded rapidly, and it can now be recollected that it was the return pipes which gave the most trouble; but it does not appear to have caused suspicion that the corrosion was not due to differences in location and treatment, or to leaks when alternately heated

and cooled as above mentioned, and so no warning has been given in respect thereto. Mr. James B. Francis, Past President Am. Soc. C. E. states that it was reported to him forty years ago that the return pipes in a certain mill were corroding very rapidly, and that the accompanying steam pipes seemed to be in much better condition, but that the matter went out of mind, and it did not occur to him again until he heard of the difficulties here in New York. One engineer, after hearing the above statement, was kind enough to inform the writer that if he had been asked he could have told about it, as he had observed the phenomena himself in the Eastern mills. Unfortunately this very person was one called in consultation by a proposed investor, while the work was in progress, and his report made no reference to anything of the kind. This fact is mentioned, more to show that even if certain persons were informed in regard to the corrosion of return pipes, it was not mentally separated from other failures by corrosion, sufficiently to cause it to be recollected and specifically mentioned; and the fact that when steam pipes and return pipes were arranged nearly together, under exactly the same conditions as respects exposure, moisture, etc., one set (viz., the return pipes), would corrode rapidly, and the other (viz., the steam pipes), would not—if indeed ever noticed more than casually, certainly was never sufficiently understood to be spoken of in conversation among experts on the subject, or to find its way into standard works. It is true that one pipe fitter would find that his return pipes had corroded, when as he thought, carried too near the cellar floor, and another when, as he thought, the moisture dripped on the same from the walls, but the fact that such pipes corroded more rapidly at or about the particular temperature of return pipes, independent of position, does not seem to have been previously even thought of.

The return pipes of the New York Steam Company finally caused so much difficulty from leakage, that the present management decided to dispense with them, and this has been done on the east side of Broadway and in many streets on the west side, by arranging that the water of condensation from the heating coils of the buildings be discharged to the sewers. This is the method originally adopted by the original Holly company, which, it is well known, has put up a large number of plants for heating buildings in small cities throughout the country. Its general plan in heating a dwelling, was to run the pipes to and from the radiators as usual, and discharge the water of condensation

from the trap through an indirect stack of coils used for heating the main hall of the dwelling, or perhaps the front of a store. In this way the temperature of the water discharged was brought down to 100 degrees in many cases, and the loss of heat and of water formed a small percentage of the total cost. This was known to the writer when originally designing the plant of the New York Steam Company, for which the conditions were entirely different. The Holly people had been working with pressures of 20 to 40 pounds. In New York it was proposed to carry 80 pounds pressure (80 to 90 pounds have been kept up continuously). The steam was to be used for operating engines, and it was absolutely necessary that the mains be drained at every dip. The water taken from these points would necessarily have the full temperature of the steam, and on allowing its escape into the atmosphere one-sixth to one-seventh of it would burst into steam at that pressure, so its direct discharge into the sewers was impracticable. Moreover, the steam was to be conducted to many buildings in which the pressure on the radiators was carried at 40 to 50 pounds. Many lessees had only one floor and the right of passage along the halls and stairs. Many basements were occupied as wine cellars, and no privileges could be obtained for those on the upper floors, except, perhaps, that of running pipes under the care of a watchman. Moreover, the new enterprise had popular prejudices to overcome and municipal regulations to consider, so a return system was provided, the same as is always used in large buildings. The difficulties about getting rid of the steam from the hot water can now be better handled than it could originally, as the company has access to many consumers. In some instances, the discharge from the street traps is brought to coils in the ventilating shafts of adjoining buildings, and the water discharged at a lower temperature. Parties who have control of the basements have in some cases had water coils placed on the returns for heating some part of the building, as in the Holly system. In other cases, arrangements have been made to heat radiators in one part of the floor with steam, and those in other parts with hot water discharged from the trap, though in such cases the distribution of heat is not always as desired. It is, however, difficult to carry out this system perfectly, as originally feared; and considerable steam is finding its way to the sewers, and at places escapes from the sewer manholes in large volumes. The company has adopted the policy of letting each consumer take care of his own water of condensation, so as to avoid discussions in relation thereto with the Department of Public Works.

There have also been serious difficulties with leaky joints, on the steam mains of the New York Steam Company. As is well known to the New York members, the work was prosecuted under the most aggravating conditions of disorganization, which it seems necessary to refer to with sufficient detail to form a sort of engineering precedent, in relation to one of the most difficult problems an engineer is obliged to encounter. With the best of feeling, and with due respect to all concerned, it seems proper to say that the President and promoter of the Company, though a most charming person socially and intellectually, was, when he made his advent in the East, an unusually bright specimen of the Western "hustler" who believed in "looking after things," as it was called; and no amount of persuasion or argument could at first impress him with the necessity in executing a difficult and important work of this character, of organizing and building up a corps of well informed, skillful and reliable employees, who could be trusted to do good work even when out of sight, and left without harassment, with hearts and minds free to do it. On the contrary, every one from the laborers up, was urged to hasten his own work, and called upon around the street corners, at the office, or at the hotel, to report progress and report the shortcomings of others. One gang of men in one street was pitted against those in another. The enormous difficulties in doing such work under such conditions, were aggravated by the fact that a very large amount of money, subscribed through the magnetic influence of the operator, was spent in real estate to give the Company business standing, and the constructive work was done almost exclusively with borrowed money. When the times were good and the banks loaned liberally, the work was pushed, and sometimes more rapidly than good men could be found and educated to do it; and as money tightened there might be a sudden order to reduce the wages of everybody ten per cent., independent of the condition of the labor market, or to put fifty per cent. more sand with the cement, independent of the strength of the mortar. It became necessary repeatedly to suddenly reduce the force, and it was frequently very difficult to save even the principal employees with their valuable experience and special education; and when this was done the harassment due to criticism of their efforts to keep busy without a proper working force, rapidly demoralized them, and the work started up again at the next boom with less vitality than before. The original company which had encased steam pipes in wooden logs, freely gave their advice as to the ex-

travagance of using brickwork; and it was criticised at all times, at all places, and before all men, with lamentations as to the obstinacy and extravagance of the engineer. The curtain may fall on particular details, some of which would seem to be romances. The experience of some of the older members of the Society was appealed to, as to the proper course of action in such cases, but little assistance was gained; most of the suggestions taking a ridiculous form, such as an accidental turning on of a hose and things of that kind. One prominent member of this Society, supposed to have the interests of the promoter at heart, was appealed to, but perhaps, as it proved, in rather too indirect a way, as he felt it to be his duty to report to the promoter that he feared the engineer was not as "loyal" as he should be. This, though discovered long after, partly accounts for the intensity of some of the difficulties. The relatives and business partners of the promoter were consulted, and urged to do something to get the business organized on business principles, put somebody in charge in whom there was confidence and go ahead. Our respected President of the Society, Mr. Shinn (who is not the person above referred to), was called in under the circumstances; and though able as Vice-President to do valuable service in getting the finances and book-keeping on a business basis, and in particular cases in a quiet way in doing much more, he was finally obliged to declare in regard to disorganizing matters, that the President of the Company must alone be held responsible for his acts. The writer, though eventually receiving many signs of confidence and finally promoted to the management, was engaged in a continuous contest, and found that the only way in which progress could be made was first to receive compensation suited to the character of the work; second, to work hard all day and sometimes late in the night, occupying a large portion of the time in untying the knots caused by disorganization the day before, and as much of the time as possible in supervising the design, construction, operation, and business incident to the work; when, declining invitations to discuss matters still later, he would go home and forget everything, whereby he was able to repeat the operation continuously. Under such circumstances this great work was conducted. It is not to be wondered at that some bad work was done; some due to slight imperfections in material which escaped even conscientious inspection; some due to carelessness, as for instance, screwing a drain-pipe only one thread in the bottom of a casting 1 inch thick; some due to the nervousness of the workmen in screwing up the pipes when the

quiet of the neighborhood was broken by the advent of the bundle of nerves, whereby a casting fully twice as heavy as used in ordinary work for the same pressure would be cracked sufficiently to finally give out and require the digging up of the street. Again, laziness would occasionally prevail, and a man attempt to loosen a plug by hammering it with a sledge and cracking the nozzle, instead of walking across the street and obtaining the heavy wrenches, ropes, and tackles which had been provided to perform the operation without risk. All these things, however, account for but a small portion of the difficulties experienced. The principal leakage was caused by imperfections of foundations, due to the failure to construct some of them in the way originally designed, and which was carried out until the disorganization reach its height. It will be recollected that expansion was provided for by diaphragm joints peculiar in construction, called variators, which will be referred to hereafter. They required that the pipe be divided into sections not exceeding 50 feet in length, but as the crosses at street corners must be at the terminations of the sections, the latter were generally a little over 40 feet long. In some cases there were double variators with two diaphragms at the end of the first section, then a small cross called a service box, then a double variator again. At other times there was but one double variator in a block and single variators with one diaphragm were used at the ends of the other sections. The service boxes and single variators were provided with ball joints which could be screwed up in place, thereby eliminating all strains and permitting small changes of direction. The diaphragms of the variators also provided slight flexibility. The plan was adopted of putting in brick foundations extending down to undisturbed earth, and capped with stones set to grade by the engineer, at the end of each section, and this part of the work was well done and never settled. Each section, however, was composed of three lengths of pipe, which, for the large sizes, were flanged together, and the two pairs of flanges thus intervening were, to provide for slight defects in securing the flanges, want of straightness of the pipe, etc., supported on brickwork built after the pipes were put in place on temporary blocking. Each pier was built up within about 3 inches of a flange, a cast-iron support with a flat bottom put against the flange, then the capstone of the pier was put in place and held up against the saddle temporarily with wooden wedges, when the joints on either side of the wedges were grouted, the temporary blocking removed, and the pipes remained

supported without strain exactly as they had been put together. A first it was required that the wedges be removed and the space occupied by them also cemented. This so delayed the work that permission was afterward given to leave them in place, building their ends in the side walls and depending for support upon the mortar at the sides, which was amply sufficient, as the pipes with flanges and mineral wool covering would rarely bring more than 1 000 pounds pressure on an 8-inch pier, so if the masons had carelessly only pointed up the crack at each end so as to give ½-inch of mortar for 16 inches of length, the strain would not reach that ordinarily imposed on brickwork. So important was this work considered, that particular masons were previously trained in the work by the engineer, and if another gang opened another street, this operation was repeated during all the time the work was in progress. Notwithstanding this care, some two years after the large pipes in Broadway were laid, leaks developed, and it was found that for a long stretch in this street, and at points in other streets, as appeared afterward, the cement had been left out alongside the wooden wedges, and the only support for the intermediate joints of pipe, was that obtained from shriveled and charred wooden wedges between the substantial brick piers and their capstones. Gradually but surely the pipes had settled breaking the joints not only in the flanges over the supports but frequently at the other ends of the pipes. The very slight leaks at the beginning, were gradually eroded by mechanical action, and although the slits thus formed would not ordinarily be ⅛-inch wide and half the thickness of a sheet of paper, so small in fact that they could not have been preserved for any useful purpose, yet the steam had become so free from deposit that the leaks did not close, and through the multitude of minute openings the whole soil became saturated with steam. Occasionally one of the openings attained a much larger area. Eventually every defective joint had to be dug up and the leaks stopped in various ways. The larger pipes, of which the outside diameters are given at the beginning of this paper, were secured in the flanges, by rolling with large expanders in a bell-shaped groove, the ends of the pipe abutting against a shoulder to take the longitudinal thrust. These joints had proved excellent on preliminary tests, and each pipe was tested after the expansions were made; but to provide for any possible failure, an annular groove was left in a hub-like extension so that calking material could be put in the same, around the pipe, at any time. These

spaces were originally filled with lightly driven rust joints, simply to give stiffness to the flanges. As leaks occurred, the rust joint material was cut out and lead wire driven in, copper proving so rigid that it would increase the leaks. It will naturally be supposed that screw joints would have been better, but in one locality the same action took place on 8-inch pipe with screw joints, and the leaks were worse than with the rolled joints; for the reason that the erosion cut off the points of the threads, and from the usual confidence in screw joints no grooves had been provided for calking purposes. Every one of these joints, therefore, was necessarily made tight with followers bolted on in halves and held together on opposite sides of the flanges by through bolts. The same process proved necessary also on the rolled pipe when the leaks broke out a second time, as with the slightest leak the lead would be rapidly eroded. Lead proves to be excellent even for steam joints, if means be provided to overcome its lack of elasticity. The pressure produced by comparatively long bolts, well screwed up, seems to be sufficient to accomplish this purpose. The work on Broadway, on account of the position of the railroad tracks which had been laid directly over the pipes, cost on the average more than $120 for each joint, so about $50 000 was spent on this street alone, frequently stated to be five or six times that amount. No calking that could be applied made the pipe joints as good as they were originally, so, as was expected, from time to time leaks have broken out, but not to any general extent; the steam now appearing through the sewer manholes being largely due to dispensing with return pipes, as explained elsewhere.

In attempting afterward to ferret out the reason why the cement grouting was omitted under the capstones of the intermediate foundations, the masons claimed that it was due to a direct order from parties other than the engineer; but whether it came directly from the one who had been persuaded that wood was as good as brick, or whether another who had been saved from dismissal and desired to please his benefactor, simply misunderstood the earnest conversation of the latter, and thought to please him by taking him at his word, will probably never be definitely settled.

After the difficulty developed, the cast-iron saddles were grooved on the bottom, and iron wedges applied in the grooves against the stones to hold the saddles up to the flanges on the pipe. It may be asked why this was not done in the first place, but it is submitted that the arrange-

ment first used was a proper one. The pipes were originally blocked up so that the flanges were parallel, and when bolted together lay on blocks without strain. The problem was simply to hold them there. The method adopted, where carried out, did this perfectly. On the other hand the iron wedges could be operated by careless workmen so as to lift the pipes too much, and to do as much injury by straining the joints upward as if they settled in a like degree.

It is gratifying to state that the expansion joint, used on the steam mains, has proved a success from the beginning. It has been called a variator (see Figs. 5 to 9, inclusive, Plate XIX). It will be remembered that the principal feature is an annular copper diaphragm with circular corrugations, clamped at the center to an extension of one of the pipes, and on the outside to the body of the variator. A section of a diaphragm is shown clearly in the enlarged view, Fig. 7. The diaphragm is supported on ribbed plates of radial outline, the ends of which rest on ledges as shown. The outer plates are heavily ribbed and receive the steam pressure, being protected by a curved bonnet, which also guides the central hub to which the center of the diaphragm is attached. An inner set of lighter plates are also provided to resist the pressure of the atmosphere in cooling off the pipes. In the "double variator," shown in Fig. 5, two diaphragms are used with connections for main pipes facing in opposite directions. In the "single variator," shown in Fig. 9, but one diaphragm is used, with one pipe connection like that described, and another formed by drawing the body of the variator itself in bell form down to the size of pipe. The reduced end of the body is in all cases provided with a ball joint, as shown, so that the pipes may be put together without strain and with slight differences in alignment.

These drawings also show the method adopted of connecting the services. As shown, each outlet is provided with a flange, and is ordinarily closed by a plug in the opening. It is tapped, under pressure, by first loosening the plug with a very large wrench, then bolting the valve permanently to the flange, and temporarily applying to the outer flange of the valve a tool with a central mandrel, having on its inner end a left-hand thread which engages with a hole similarly tapped in the plug. By revolving the mandrel to the left the plug is removed, the pressure admitted to the valve, and, by pulling the mandrel back and shutting the valve, a connection is made in a very few minutes, through which steam for 70 to 100 horse-power can be taken.

The general arrangement of fittings at junctions is shown in Figs. 10 to 21, inclusive. Fig. 18 shows the construction at the large elbows where the steam leaves the station, and the others show the general appearance of the pipes in the ground with conduits uncovered. Fig. 21 illustrates the flexibility of the system. The pipes were first laid in the open trench supported on brick piers, referred to elsewhere, when brick walls were built up around them so as to leave a space of about 4 inches at all points, which was filled with mineral wool in bulk. The conduit thus formed, was covered transversely with a roof of heavy plank made by sawing up the timbers of old buildings, the brick courses being arranged so that the covering was slightly inclined. An outer covering of tarred paper was extended over the planking and down the sides of the brickwork, nearly to the bottom, and smeared with hot coal tar. It was considered that dry wood, separated from the steam pipes by mineral wool, would last for many years and until the pipes would need examination. Flagstones were used in some cases, and can be applied at any time in making examinations. It is not thought that the system of constructing the conduits can be improved. The mineral wool covering is all that can be desired as a non-conductor, and appears to be efficient for this purpose, but a less quantity can probably be used without a serious loss of heat. A flagstone covering would be more permanent, though the wood, even during recent examinations, proves to be in excellent condition, and is charred slightly only where subjected directly to a considerable steam leak.

An important question arises as to how return pipes should be constructed in locations where it is desirable to use them, in view of the corrosion which has taken place in such pipes in New York. It has been the opinion of the writer that the true course of action is simply to use rolled brass pipe instead of iron, and to continue to make the fittings of heavy cast-iron as heretofore. The additional cost of brass pipe is well warranted. It will be found on calculation that if the feed water of the boilers be pumped into the boiler at a temperature of 200 to 212 degrees, instead of that of the ordinary city supply, there will be a saving of about 10 per cent. in fuel. Further, it will be found that the amount of coal consumed in a district system per year, will equal or exceed in value the cost of the pipes necessary to distribute the steam which such fuel will generate. It follows, then, that if 10 per cent. of the fuel is saved, that this saving will pay 10 per cent. on

PLATE XIX
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FIG. 11.

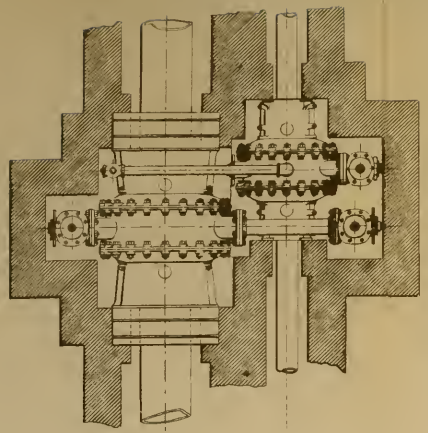


FIG. 13.

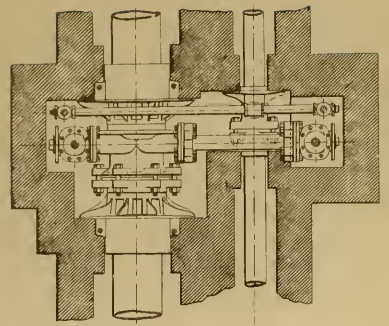


FIG. 15.

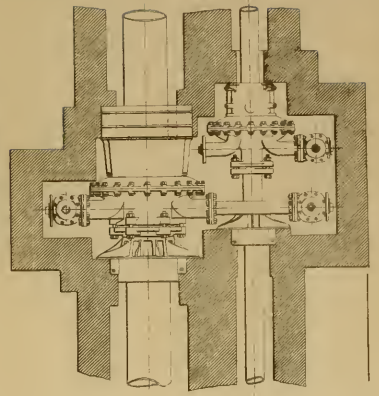


FIG. 17.

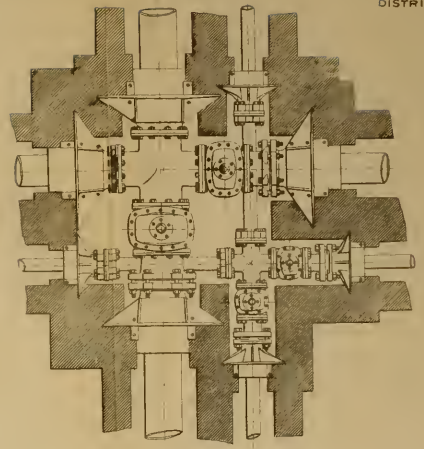


FIG. 10.

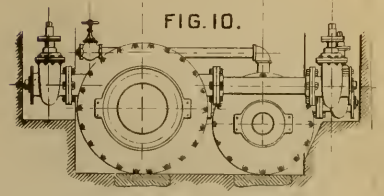


FIG. 12.

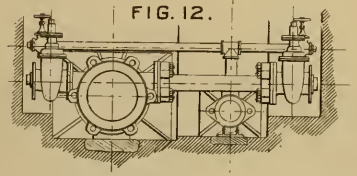


FIG. 14.

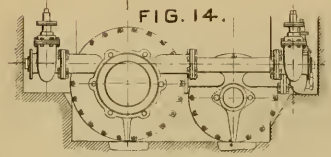


FIG. 16.

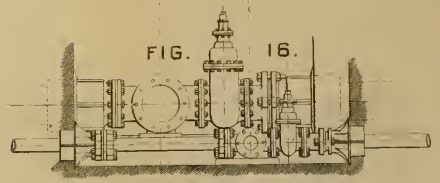


PLATE XX
TRANS AM SOC CIV ENGRS
VOL XXIV Nº 455
EMERY ON
DISTRICT STEAM SYSTEMS

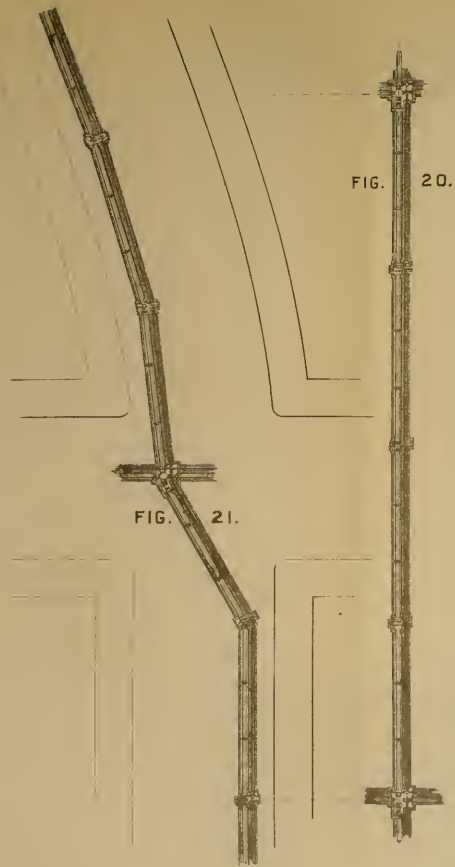


FIG. 20.

FIG. 21.

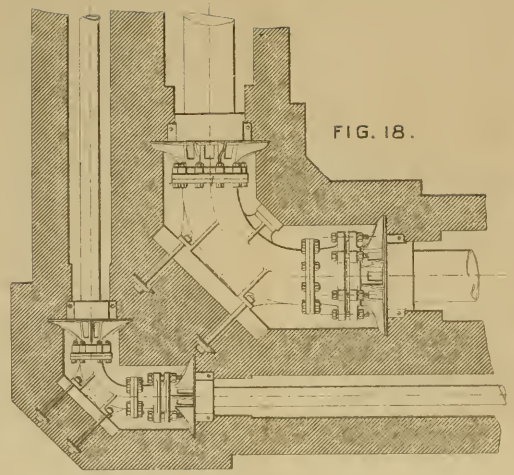


FIG. 18.

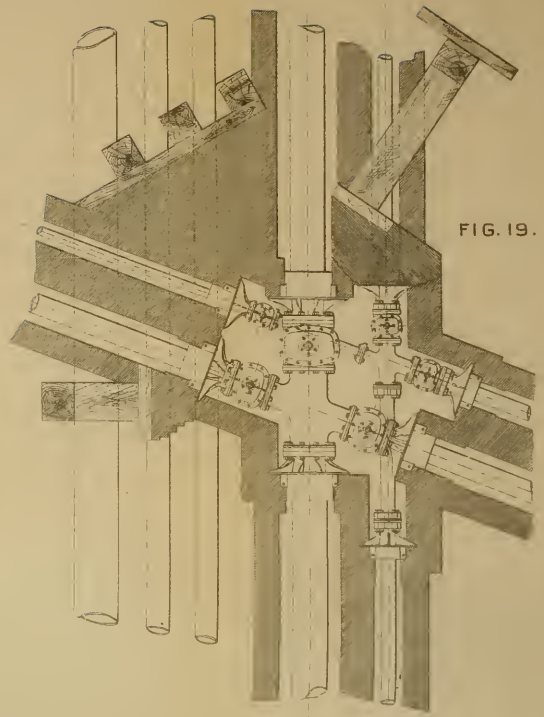


FIG. 19.

the ordinary cost of the pipes of the street plant; so that even if the smaller return pipes be made of brass, there will still be left a very excellent percentage of profit on the whole cost, due to the use of return pipes. These conditions do not apply to cheap heating plants, as explained elsewhere, so the problem whether return pipes be used must be settled by the conditions of each particular case.

The general question will naturally arise whether the district steam systems as at present developed have been sufficiently successful to warrant the construction of other plants. In response it may be stated, that there is only one class of buildings to which steam cannot be supplied at a profit from an external source, viz.: the large modern buildings, in localities where there is no legislative restriction as to the erection of steam boilers on the premises. The coal used in such buildings can in general be bought nearly as low as by a steam supply company, the same type of boiler can be used, and even if the relative price of labor is somewhat higher than at the buildings of the supply company, this only balances the profits of the latter company, so that there is no incentive for the proprietor of the building to make a change. However, it is only the largest of these buildings that have the space, and have been constructed with the foresight to enable a plant of this character to be used. In very many buildings the steam plant has been the last thing considered, and is either too small, or put in such a place that the heat from the boilers impairs the rental value of basements and other parts, so that a supply of steam from a district system will be taken if the difference in price is not too great. There is, however, another class of buildings to which the district supply is a great boom, viz.: buildings of a smaller type which have little facility for the erection of boilers, and in which the cost of attention would be comparatively high. There are a large number of these buildings in New York, which, with steam supplied from the street, have put in elevators, steam heat, and increased water distribution; and are thereby able to compete with larger buildings in the rental of comfortable and desirable offices.

The District Steam Company cannot hope to permanently supply a very large quantity of power at a particular location, except to an enterprise associated with it in a business way; but all the electric light plants will start their business by purchasing steam, and be happy to pay for continuing a connection to be used in emergencies afterward. Again, there is in every city a demand for power and heat, in small manufactories.

In New York there is a surprising number of such located in the lofts of buildings, in many of which the other floors are occupied for other business purposes. In this way ample power is obtained, in locations where the simple handling of the coal and ashes to portable engines, would make the use of the latter prohibitory. On the whole, it will be seen, then, that the steam system is a great public convenience, and the commercial question in regard to further constructions of the kind must depend upon various financial and local conditions. There can be no question but that if a large number of property owners in a given district would associate themselves together, and put up a steam plant for the improvement of their property, the enterprise would be a remunerative one, even in a business neighborhood. It is doubted, however, if in such a neighborhood the profits realized would be such as to warrant the intermediate action of promoters and large issues of stock. In a neighborhood of dwellings of well-to-do people there is, however, a very large and important field for district steam systems, particularly if the steam be simply used for heating purposes during the period heat is required, and the plant be shut down in summer, so that the operating expenses are saved. Plants of this kind pay well even in the coal regions of Pennsylvania. In the bituminous regions the residents use anthracite coal in their houses, because it is less liable to injure the furnishings by dust and smoke, whereas a district steam company can, in an out-of-the-way place, burn the slack of the bituminous coal, purchased at a little more than the price of haulage. In other cities, whether near or far from the coal regions, coal of large size and good quality is used in the furnaces and steam boilers of the wealthy and well-to-do, while a steam supply company can use fuel of a very inferior kind, purchased in quantity at a very greatly reduced cost. If, then, the steam plant be constructed cheaply, as is possible with a pressure not exceeding 40 pounds, it is believed that heating systems of this kind will pay in any dwelling neighborhood, even when the houses are widely separated, with considerable ground around each. In locations where water is cheap, water coils can be used to utilize the waste heat from the rejected water.

It is predicted that the largest use of steam will eventually be in foreign countries, where there are restrictions upon the erection of steam boilers in the city limits. In such cases the plant of the New York Steam Company would practically be duplicated (under conditions, of course,

making it possible to obtain good work). There would be both a main steam pipe capable of distributing steam at high pressure and a return pipe, so that the hot water and steam would be kept out of the sewers. Such a plant, for reasons above stated, would add greatly to the value of property along the line, and the prices which would be obtained would insure a good interest on the investment. It would be entirely practicable in some cities to carry out a plan proposed for San Francisco, to wit, to use high steam pressure in the manufacturing and office neighborhoods, discharge the exhaust steam into other steam mains, and conduct the same to dwelling neighborhoods in the vicinity, for heating purposes, from which the return water would either be discharged into the sewers at a low temperature under proper supervision, or if water was high priced, be returned to the station.

(The discussion on this paper was taken with the one by Mr. Worthen which follows.)

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

467.

(Vol. XXIV.—March, 1891.)

STEAM HEATING.

By WM. E. WORTHEN, Past President, Am. Soc. C. E.

WITH DISCUSSION.

I have thought that it might be interesting to the members of this Society to give as a sort of supplement to the paper read by Dr. Emery, on "Steam Heating," an outline of the history of heating as applied to the heating of the cotton mills at Lowell. My early life was passed there, from its first inception as a manufacturing center in 1822, up to 1849, and I had especial opportunities as a boy in going over the mills, and afterward as an engineer in their construction.

The earliest cotton mills were heated by hot-air furnaces, one at each end of the mills. The mills were about 150 feet long by 50 feet wide, with furnaces at each end as shown in Fig. 2, Plate XXI, with brick flues opening into each story. The furnaces were cast-iron boxes with corrugated top and sides cast in one piece, and of length to admit cordwood of the usual 4-foot lengths without sawing. The furnaces were enclosed in small brick buildings, arched over in brick, and to protect the mortar joints of this arch from the weather it was covered with sheet lead. As the lead expanded from the heat beneath and from the sun, it hung down from the eaves in fringes, and as it had not cohesive strength to draw the fringes back in cooling, they hung there till cut off from time to time. Eventually the lead

parted at the ridge, like many financial schemes in which the construction account is kept open, declaring dividends from apparent surplus, with at last a central burst at the ridge.

Hot-air furnaces with brick flues were put into the houses of the mill agents, and the first church, consecrated in 1824, was an example of a closed hot-air circulation. The furnace was placed beneath the center of the church with the usual hot-air chamber of brick. The cold-air duct drew from the end of the church, just inside of the doors, and the hot air was delivered into the center through an aperture directly above the furnace.

At this time wood was the only fuel. Steam was introduced about 1836, boilers were placed in the old hot-air furnace houses, and the steam-pipes were 3 to 6 inches of cast-iron suspended from the ceilings, the steam and drip connections being of small wrought-iron pipe. It has been very difficult to find out when wrought-iron pipe was first introduced. I understand from Morris, Tasker & Co., that "the butt welded pipe was first made in this country about the year 1830 to 1832." In the early editions of Appleton's "Dictionary of Mechanics," under the head of forging, it says: "Musket barrels, when made entirely by hand, were forged in the form of long strips about a yard long and 4 inches wide but taper both in length and width, which were bent round a cylindrical mandrel until their edges slightly overlapped; they were then welded at three or four heats, by introducing a mandrel within them instantly on their removal from the fire."

When the illumination by gas was at first introduced in the large way, by Aaron Manby, Esq., then of the Horsley Iron Works, England, old musket barrels were employed for the conveyance of gas. The breech ends of the musket barrels were broached and tapped, and the muzzles were screwed externally, to connect the two without detached sockets. From the rapid increase of gas illumination, old gun barrels soon became scarce; this led to a series of valuable contrivances for the manufacture of the wrought-iron tubes, commencing with Russel's patent in 1824, under which the tubes were first bent up by hand hammers and swages to bring the edges near together. They were then welded between semi-circular swages, fixed respectively in the anvil, and the face of a small tilt-hammer worked by machinery, by a series of blows along the tube, either with or without mandrel. The tube was completed by being passed between rollers with half-round grooves, which forced it over a conical

or egg-shaped piece at the end of a long bar, to perfect the interior surface.

In a communication in 1882, of the late Robert Briggs, M. Am. Soc. C. E., to the Institution of Civil Engineers, of which he was also a member, it is stated that the late Joseph Nason, of Boston and New York, was the originator, improver, and adapter of much that is essential and now implicitly followed, in the general arrangement and details of the apparatus employed in the American practice of heating buildings by steam. I knew Mr. Nason very well, and recollect about 1840, when a very young man, he returned from England and endeavored to introduce Perkins's system of heating by hot water circulation through small pipes. He attempted to heat one of the dye kettles of the Merrimack Print Works in this way, but did not succeed. He put hot water apparatus into the houses of some of the agents of the mills which worked well. He soon turned his attention to steam heating, with the results as given above by Mr. Briggs. With regard to the Perkins system of heating with hot water, in the *Journal of the Franklin Institute* for September, 1837, is the following quotation from a letter from Jacob Perkins written in 1836: "My son Anger is doing well with his patented apparatus for heating by hot water. The system of heating by hot water and steam is being abandoned, and the old apparatus removed from various public buildings to give place to the new. This is the case in the British Museum, where Anger has given great satisfaction. It would seem incredible, but it is a fact, that in this apparatus a stream of hot water which is not thicker than your little finger, carries the heat 700 feet, and then returns to the boiler at a temperature of 100 degrees. The boiler is a coil of tubes of the same diameter with the conducting pipe."

The steam-pipes, as placed in the mills by Mr. Nason, were arranged along the inside of the wall and were, I think, at first trombone coils, that is, the circulation was through a single pipe returning by a single half-turn or return bends, and so continuously from one end to another according to the number of pipes required. Afterward branch tees or manifolds were introduced, expansion being provided for by right-angled bends in the pipes at the end of the room; afterward these bends were turned up vertically, making mitre branches with the horizontal lines.

At present the Boston Manufacturers' Mutual Fire Insurance Com-

pany recommend the placing of the coils of steam pipes for heating purposes overhead in mills, in almost all cases.

When the heat was first introduced to heat the mills, as said before, the small hot-air furnace buildings were used as boiler houses. The boilers themselves were vertical, and were fired by watchmen who had many other duties. They carried thick fires, and the feed-water was supplied automatically by balanced stone floats, which drew water from cisterns in the attic of the mills, supplied by three and five throw single plunger pumps driven by water wheels. These pumps and cisterns were also used for mill and fire service.

The form of the old boilers has passed out of remembrance, but I give a section of one, Fig. 4, Plate XXI, introduced by James B. Francis, Past President Am. Soc. C. E.; and the results of experiments made by him in 1841 on the evaporation of two boilers used for heating the Massachusetts Cotton Mill No. 2.

Area of grate surface in each boiler...	3.20 square feet.
Area of fire surface.....	126.50 "
Duration of experiment.....	115.52 hours.
Total number of pounds of coal burned	5 283 pounds.
Total number of pounds of water evaporated 866×62.375.....	54 016.75 "
Temperature of feed water.....	32 degrees.
Pounds of water evaporated from one pound of coal from initial temperature $\frac{54\ 016.75}{5\ 283}$	10.225 pounds.
Pounds of water evaporated from one pound of coal from 212 degrees $\frac{180 + 1\ 000}{1\ 000} \times 10.225$	12.065 "
Pounds of coal burned per hour on one square foot of grate surface $\frac{5\ 283}{2 \times 3.2 \times 115.52}$	7.146 "
Pounds of coal burned per hour to each square foot of fire surface $\frac{5\ 283}{2 \times 126.5 \times 115.52}$	0.181 "
Square feet of fire surface to one square foot of grate surface.....	39.53 "

The above was given me by Mr. Francis many years since, and I have preserved it as an example of excellent practice, simple in construction, and economical in results ; and my opinion has not changed after testing many and varied forms of boiler. Mr. Francis now writes me of the results of two other trials of one hundred and twenty hours each:

"February 22d to 27th, 1841. 10 245 pounds of water evaporated by 1 pound of coal.

"February 15th to 20th, 1841. 9 917 pounds of water evaporated by 1 pound of coal."

The temperature of water supplied to the boiler is not given, but it could not have been much above 32 degrees.

Before 1840 the mills had a nearly stereotyped form and size, but soon after, the capacity of the mills as to machinery and product began to be increased, and at the present time the Manville Cotton Mill No. 2, Plate XXI, Manville, R. I., is probably as large as any. It is 783 feet long by 98 feet wide, and four stories above basement, 120 000 spindles. The illustration, Figs. 2 and 3, shows relative size of this and an old Lowell mill, and the location of the boilers. With the first increase of size of mills at Lowell, the spaces between the mills were utilized, supplementary steam-engines were introduced (the first one under my charge at the Hamilton Mills in 1845), and the boilers for steam heating and power were concentrated in one building, and put into the hands of efficient stokers. This arrangement obtained at Printing and Dye Works earlier.

In my address at Kaaterskill I alluded to a report made by me in 1866, to the Merrimack Manufacturing Company, of Lowell, on the economy of using high steam for power at the cotton-mills; and afterward the exhaust at their print works for the purposes of heating, boiling, etc.; and suggested passing the steam through engines of 1 200 horse-power, and using the exhaust steam afterward in the print works, with a back pressure of about 6 pounds. I also stated that the amount of coal properly chargeable to power in this case would not exceed 1 pound of coal per horse-power per hour. It was a success, and of its present extent the superintendent of the works writes me as follows: "We have only one pair (34 × 72 inches) condensing engines on our premises, all the others (something over a hundred cylinders) exhaust into a system of mains, from which we draw all the heat we require. What we do not require for heat we take into the condensing cylinders before mentioned, and reconvert into power."

E. D. Leavitt made a test of this steam plant and furnishes the following interesting results: "Three trials were made in 1877, two of which were of the cotton yard plant, and one of the print yard machinery. All the steam made by the boilers tested was passed through the engines. The trial was extended over a period of one week. One engine of the cotton yard plant was run condensing, and one non-condensing. In the first trial, extending from August 27th to September 1st, inclusive, four of the vertical Corliss boilers were used; in the second trial, but three were used, the intent being to determine the potential evaporation of the boilers.

The total amount of coal used on the first trial was.....	181 574.9 pounds.
The total amount of coal used on the second trial was.....	196 082.0 "
The total amount of water evaporated on the first trial was.....	1 508 929.33 "
The total amount of water evaporated on the second trial was.....	1 628 496.56 "
The amount of grate surface on the first trial was.....	413.08 square feet.
The amount of grate surface on the second trial was.....	309.81 "
The amount of heating surface on the first trial was.....	15 826.28 "
The amount of heating surface on the second trial was.....	11 869.71 "
Gross combustion per square foot of grate on first trial was.....	7.326 pounds.
Gross combustion per square foot of grate on second trial was.....	10.54 "
Coal consumed per 1 horse-power per hour by condensing engine, first trial.....	2.3289 "
Coal consumed per 1 horse-power per hour by condensing engine, second trial.....	2.4115 "
Coal consumed per 1 horse-power per hour by non-condensing, first trial.	3.5348 "

Coal consumed per 1 horse-power per hour by non-condensing, second trial.....	3.7700 pounds.
Deducting all heat supplied for dyeing, heating and boiling by the exhaust of the non-condensing engine, the amount of net coal per 1 horse-power per hour becomes on first trial.....	.67817 "
Deducting all heat supplied for dyeing, heating and boiling by the exhaust of the non-condensing engine, the amount of net coal per 1 horse-power per hour becomes on second trial.....	.5816 "
It was estimated that the mill power per day with the condensing engine, cost on the first trial.....	$6 58
It was estimated that the mill power per day with the condensing engine, cost on the second trial.	6 74
Cost of mill power per day with the non-condensing engine on the first trial.....	1 77
Cost of mill power per day with the non-condensing engine on the second trial.....	1 56

The difference being due to the value of the exhaust of the non-condensing engine for boiling and heating."

In a late letter the following explanation was given of the methods of conducting and analyzing the experiments: "We took, in each test of one week, over one thousand indicator cards, all of which were computed for volumes. The total coal consumed in the trial was then divided, in proportion to the volume of steam exhausted by the condensing and non-condensing cylinders, and the coal per 1 horse-power per hour was computed on this basis, being for the non-condensing engine 3.5348 pounds per horse-power per hour, and 2.3289 pounds per horse-power per hour for the condensing engine." "All the steam used by the non-condensing cylinder, less that used for conversion into work, was available for heating and dyeing. Adding this less amount to the coal consumed by the condensing engine,

and dividing by the total indicated horse-power, is what gave the true result of coal per horse-power per hour. In the estimate of the cost per mill-power by condensing and non-condensing engines, we took the interest on the cost of the plant, wages and supplies; but inasmuch as the boiler plant would have to be maintained and the employees be practically the same whether the engines were there or not, for supplying the dyeing-house and drying-rooms, the wage account for the non-condensing engine became very small."

A mill-power at the Merrimack mills is 25 cubic feet of water per second on a 30-foot fall. Allowing a loss of head and fall of 1 foot for getting the water to and from the wheel, the net fall will be 29 feet.

$$\frac{\text{25 cubic feet water per second x 62.4 weight per cubic foot x 29-foot fall}}{550} = 82.24 \text{ h.-p., gross.}$$

Estimating the percentage of effect of the water on the wheel at 80, $82.28 \times 80 = 65.79$ horse-power, net. It is usual to consider a mill-power 65 horse-power effective. In this connection I give a simple rule for estimating the net horse-power of a water-power: It is to multiply the effective fall by the flow per second in cubic feet, and divide the product by 11. Example: $\frac{\text{29 feet x 25 cubic feet}}{11} = 65.9$ horse-power.

From Mr. Leavitt's paper above we obtain:

Estimated mill-power per day with condensing engine, cost on the first trial	$6 58
Estimated mill-power per day with condensing engine, cost on the second trial.....	6 74
The average $= \frac{13.32}{2}$, and $\frac{6.66}{65}$ gives a cost per day per horse-power of.....	10.2 cents.
Estimated mill-power per day with non-condensing engine, cost on the first trial	$1 77
Estimated mill-power per day with non-condensing engine, cost on the second trial.....	1 56
The average $= \frac{3.33}{2}$, and $\frac{1.665}{65}$ gives a cost per day per horse-power of.....	2.55 cents,

or say ten cents per day of ten hours per horse-power for condensing engine; or say two and one-half cents per day of ten hours per horse-power for non-condensing engine. As this steam-plant is of great interest to the profession, I have, through Mr. Francis and Mr. Ludlam, the Super

intendent of the mills obtained a plan of the works, Fig. 1, Plate XXI, showing the position of steam and exhaust-pipes. The smaller steam-engines are not marked in the plan; they all draw from one steam-pipe and exhaust into another pipe. The following is the schedule furnished me:

In the Cotton Yard.

One condensing engine, nominally about 1 300 horse-power, but usually running one cylinder only, giving about	400 horse-power.
One high-pressure engine, nominally 1 200 horse-power, usually running	600 "
One Buckeye pressure engine	500 "

The high-pressure engines exhaust into a system of pipes, extending over both cotton and print yards, carrying 8 or 9 pounds pressure. Usually about 25 per cent. of the steam goes to the print yard. All the heating and dressing in the cotton yard is supplied from the balance.

In the Print Yard.

All the engines are non-condensing, and exhaust into the general system of low-pressure pipes.

One engine	350 horse-power.
One engine	150 "
One Buckeye engine for electric lighting	150 "
Twenty engines running printing machines, called 15 horse-power each	300 "
Ten other small engines, called 10 horse-power each	100 "

All the steam is supplied from one boiler-house, pressure in boilers 85 pounds per square inch. There are but two common stuffing-box expansion-joints on the straight parts of the steam, and none on the exhaust-pipes. Expansion is met by the bends in the pipes, the pipes are protected by the Ober Steam Jacket, which consists of a covering of paper, wood or iron, supported on a flexible metallic frame, which gives the required space for mineral wool or other packing, the whole being securely bound together by metallic bands.

It will be seen from Mr. Leavitt's results, and the practical operation of the steam plant at the Merrimack Mills for a long term of years, and still in use, that if such a plant could be arranged in a city for power and

heating, it would result in great reduction of fuel, with all the economies expected to be secured by central steam-heating plants. The great difficulty of carrying out such an arrangement of steam and exhaust pipes, is to secure a good position for them. By all experience, it has been demonstrated that steam-pipes should be easy of access. In the later progress of the work of the American Steam Heating Company, I was called in as consulting engineer, and gave my advice to make tunnels at a low grade just above tide, so as not to interfere with water, gas or sewer pipes, that no disturbance of the streets would be necessary for their construction, or for their connections; that in the lower part of the city, where the strata is sand, a pipe either of wood or iron, of sufficient section to contain steam and exhaust pipes, could be readily forced through from the tunnel to the building requiring steam, as I had myself done; and in rock, the diamond drill would readily drive proper holes. It is evident that if this had been done, the Merrimack Mills arrangement could have been readily carried out. Unfortunately funds were falling off and the company could not adopt my advice. I suggested that this tunnel should be of a capacity for high-pressure water pipes which we very much need, for gas mains, and for electric wires, connections to be made similarly to those proposed for steam. Later I devised a viaduct 70 feet high for the same purpose, and Mr. T. Cooper, M. Am. Soc. C. E., kindly made a sketch of a form of construction, and estimated the cost. It has not been built.

Of the great convenience of water mains on the roofs of the houses, there is no doubt. It is recommended by the N. E. Mutual Fire Insurance Companies; the head is always maintained, and it controls the stories inaccessible from the usual water mains. This makes it also valuable for all domestic and building service. Should rapid transit ever develop into rails of such an elevated location, arrangements should be made in connection with them for steam, water, gas, and electric service, and with the present elevated railroads, the vacant space between the trusses could be advantageously used for these purposes.

In the section of the stone boiler float, which was made from memory, the water-line is about the center of the float (see Fig. 5, Plate XXI). No provision was made for balancing the area of the rod or stem of the float, and the water-line varied on that account. There was probably a stuffing-box, but this I judge unnecessary, as I had a plunger steam indicator of $\frac{3}{8}$ of an inch diameter which moved readily and was steam

tight under a pressure of 200 pounds to the inch. It would be possible to make the stem of the stone float $\frac{1}{8}$ of an inch diameter in like manner, and the consequent variation of water-line under variation of pressure would be unimportant.

In answer to the question whether the condensed water in the exhaust pipe was used at the Merrimack Mills, Mr. Francis writes me "All the condensed water from all the mills and the print works, except from the low-pressure engine and what necessarily remains in the kettles, etc., in which water is heated by admitting steam, is carried back to the boiler-house, when it is pumped through a "Green Economizer," where it is heated up to about 150 degrees and used for feed-water.

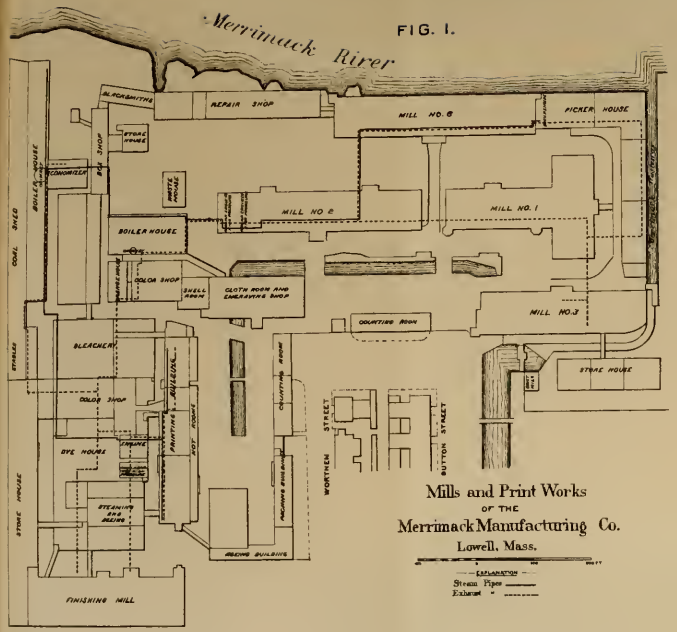
DISCUSSION.

James B. Francis, Past President Am. Soc. C. E.—The arrangements of the Merrimack Company have been entirely satisfactory. The mills are run by water and steam power together. They find great economy in using non-condensing engines. In the Cotton mills, where heat is required, no steam is drawn directly from the boilers for heating purposes, but the exhaust from the engines is used. Practically, the power is all clear gain so far as the fuel is concerned. The exhaust is made under a back pressure of about 8 lbs. to the square inch into a system of low-pressure pipes, 6 inches to 18 inches in diameter, which extend over the works, and from which steam for heating is drawn at any point where it is needed. There is a loss in carrying the steam, of perhaps 3 or 4 pounds to the square inch (about 4 pounds the man in charge told me) at the point most distant from the engines; so that there seems to be no difficulty in distributing the heat in the pipes, if you do not undertake to do it on too big a scale at once. This property covers about 20 acres.

The non-conducting material covering the pipes to prevent condensation is really mineral wool, which is a kind of glass, spun in very fine threads, protected by a woolen covering on the outside. A photograph taken in winter for the purpose, shows the snow and ice laying upon the pipe, thus indicating very little loss of heat.

The water of condensation is collected in a system of pipes extending over the works and returned to the boiler-house by gravity, where it is pumped back into the boilers, the pipes passing through a Green economizer, where it is heated to near the temperature in the boilers.

FIG. 1.

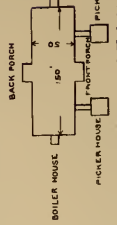


Mills and Print Works
OF THE
Merrimack Manufacturing Co.
Lowell, Mass.

EXPLANATION
Steam Pipes
Exhaust "

FIG. 2.

FIG. 3.

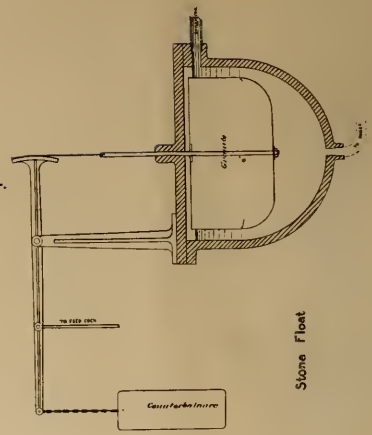


MANVILLE MILL RHODE ISLAND

TYPE OF OLD MILL AT LOWELL, MASS.

FIG. 4.

FIG. 5.



Stone Float

Charles E. Emery, M. Am. Soc. C. E.—I am very much gratified that my paper has been the means of bringing out a statement of the experience, in the same general direction, of one we have known and respected for years. Steam heating, considered simply as a business, has been practiced with some measure of success by every steam-fitter throughout the country, but such business is really founded on scientific principles worthy the efforts of engineers of talent who have had the best opportunities. This is shown by the results accomplished by the author of the paper and his associates, long before steam-fitting as a business became established, and it will be seen that recent efforts are but modifications of the developments so thoroughly worked out years ago in the Eastern mills. The paper is a valuable contribution to the records of the Society, and I trust may have the effect to induce others to state their experience in this and other lines.

The suggestions in the paper are in part being carried out. There are many buildings in large cities which are heated entirely by exhaust steam, and in a very few cases the surplus is distributed to adjoining buildings. It has been suggested to connect the exhaust pipes of the engines of various establishments to a street main, and distribute the steam exactly as was done in this mill. The idea has been previously suggested, and was carried out in the steam plant at Lynn, which failed for financial reasons connected with the organization of the company. A plan has been worked out in detail, to collect the exhaust steam from the engines in the business districts of San Francisco, and conduct it to the closely adjacent resident district, but the scheme has not yet received sufficient financial support. Such a system is not generally applicable, on account of the multiplicity of connections. In a large city, it is undesirable to waste the water of condensation from heating coils; first, on account of the value of the water itself; second, on account of the heat it contains; and third, on account of the inevitable nuisance arising from discharging hot water into the sewers. With proper water coils, little more than tepid water should be discharged, but in cities many users do not have the space, and many that could arrange that feature are not inclined, on account of the cost, to provide such coils, so that water at a high temperature, which will discharge a considerable percentage of steam in cooling, is admitted to the sewers, to the injury of the brickwork and the discomfort of the public. It follows, then, that a proper exhaust system must have three pipes; first, the main steam-pipe; second, the low-pressure or exhaust-pipe to supply steam for heat, and third, a return water pipe. This makes the number of connections so great that the system is not practicable, except where the location is particularly adapted to its use. In 1882, when connecting a large electric-light plant in Fulton street to the mains of the New York Steam Company, a section of a large main was laid with outlet to receive the exhaust from the engines, but no exhaust connections were made, as other work demanded imme-

diate attention, and the buildings in that particular vicinity were occupied by a large number of small tenants, so that there was no unanimity of action in taking steam for heating purposes. In San Francisco the manufacturing and business district is so well defined, and yet located so near a well defined resident district, that the plan is particularly applicable.

In the introduction of exhaust steam for heating, it was realized that the mains must be larger than when steam of higher pressure is circulated, so that the system appeared to be limited to new buildings, or those in which steam pipes were applied for the first time. This difficulty has been overcome, comparatively recently, by the connection of an air-pump to the lower end of the return-pipes, so as to produce a partial vacuum and induce a current in that direction, even when the steam for heating was supplied at a comparatively low pressure from the exhaust of steam-engines. In some cases the air-pump is supplemented with a condenser which reduces the amount of vapor to be handled. This device should not be necessary when the return-pipes are so arranged as to act as heating surface.

Mr. William J. Baldwin, M. Am. Soc. C. E.—There is danger from grease being carried into the boilers whenever the exhaust steam of an engine is used for heating purposes. The exhaust steam is sent through the building, condensed, and returned to a tank and pumped from the tank into the boilers. This has been the custom in a great many places, and forms an element of danger to the boilers. In the Massachusetts Institute of Technology, they made no provision at first for separating the grease from the exhaust steam and carried it (the grease) into the boilers, and ruined all the boilers. The same thing is often done in New York; there are some buildings that have special provisions for removing the grease, and lately there have been several patents for separating grease from the exhaust steam. Such an apparatus is shown in Fig. 6. When the steam leaves the engine it is carried through the pipe *a* into the tank, and projected into the water in the tank *T*. The water and grease are directed against the water already in the tank, and a great deal of grease is taken up at once, then the comparatively clean steam passes on through the pipe *b* into the boilers. There is such an apparatus in the Manhattan Company's Bank in Wall street, which has been in use about five years, and you will find no oil in the receiving-tank.

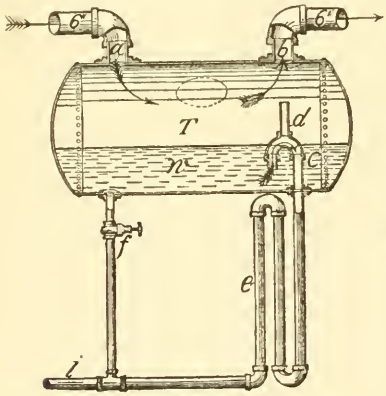


Fig. 6.

Mr. Worthen.—I think the one in the Equitable Assurance Company's building was very successful; it had a blow-off on the top.

A Member.—There is one in the Stewart building that takes four large distributing-mains from different parts of the building.

Frank W. Skinner, M. Am. Soc. C. E.—What is the condition of the return-pipes of the mills, with regard to corrosion; do they suffer seriously from it?

Mr. Francis.—I cannot say, from my own experience, but it is generally understood that wrought-iron pipes carrying warm water, rust badly.

Mr. Worthen.—The water at about 120° Fahr. bites into the pipe very strongly, but above or below this it does not affect it.

W. Howard White, M. Am. Soc. C. E.—I had a little experience bearing on the last question. Some years ago, for the Chicago, Burlington and Quincy road, at Burlington, Iowa, we heated the depot from a round-house about 1 500 feet away. The calculation made at the time, showed that the saving by returning the water to the boiler would not be sufficient to pay for the extra cost of the return-pipe, so we left that out and discharged the water. Afterward I saw the Master Mechanic of the road and he told me that the steam-pipe had been corroded by the water. It was attributed to the want of a return-pipe. He thought if the water had been returned, having only the same amount of acid which had been neutralized by its first passage through the pipes, the corrosion would not have occurred; I had no opportunity of knowing how correct his theory was. At the shops of the company outside of town the water was all returned, but I do not remember asking him whether they found it a great advantage. The inquiry would have been somewhat vitiated, too, because at that point we had different water.

Mr. H. W. Brinckerhoff, M. Am. Soc. C. E.—A very intelligent man who had put in a great deal of the old-fashioned hot water apparatus, without an expansion tank, once told me he had worked up to pressures as high as 1 200 pounds per square inch, and added that he had seen the flowpipe from the boiler visibly red in the dark; in other words, the water was red-hot. I was rather inclined to think that he might be correct, incredible as it seemed, because, on looking up the matter, I found that steam at 1 200 pounds per square inch has very closely the temperature of iron at a red heat in the dark. Besides, I was influenced by the example of a very polite Frenchman, who, after listening to a story related by a friend, said: "If you say you have seen it, I will believe it, but I would not believe it if I had seen it myself."

Mr. Worthen.—You will find in Perkins's treatise on hot water, he states as a particular fact, that the pipes get red-hot.

Mr. Baldwin.—Mr. Perkins provides an expansion tank; he expands

into the tank all the steam that is formed, so that the pressure on the water in the apparatus is elastic, the circulation goes on below it.

Mr. Worthen.—Suppose it did not circulate, would it get red-hot?

Mr. Baldwin.—Yes, sir.

Mr. Emery.—There is another point which, I think, should go on record in this connection, viz: the practice in some cotton mills. In moderate sized mills of a few thousand spindles, but a small portion of the exhaust steam is required for heating. The engines are generally double, and connected to the opposite ends of the engine shaft. With these Mr. Corliss adopted the plan of exhausting one end only of one cylinder to a low-pressure steampipe, and exhausting the other end of the same cylinder and both ends of the other cylinder to the condenser; thereby obtaining for three-quarters of the engine-power the economy of a condensing engine, and utilizing the steam for the other one-quarter, first, for power, and afterward to supply the low-pressure steam required in the mill for heating, "slashing" and similar purposes.

Mr. H. W. Brinckerhoff.—I would like to ask if anybody here has seen anything of the practical working of what is called the steam loop; it was illustrated in *Engineering News*, and has been on exhibition in Cortlandt street. I have never seen it in operation myself, and thought if any one knew of its working, it would be interesting to have it described. It is something like the sketch shown in Fig. 7.

A is a steam boiler from whose dome, *B*, steam is taken in the usual way through pipe *D* to, say a system of heating pipes represented by the radiator or flat coil *E*, from whose lowest point *F*, a pipe, *GHI*, leads back to the boiler, which it enters below the water line. The apparatus is designed to return the condensed water to the boiler from a point below the water line, without a trap or any moving parts, and is said to operate as follows: Steam having been raised in the boiler, the valves *C* and *O* are opened, and steam blown through all the pipes to clear them of air. Valve *O* is then closed, and the steam condenses in the vertical pipe *I* until it reaches a height, say *M*, sufficiently above the water-line at *N* to make up for the diminished pressure in the heating system, and, with its assistance, to overcome the pressure in the boiler and flow into it through the check valve *L*. This action, once started, is said to be continuous and rapid, the water accumulating at *F* being swept through pipes *G* and *H* in the form of spray, or carried through them in plugs or short pistons, alternating with small quantities of steam which is con-

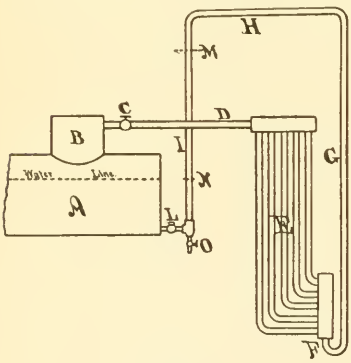


Fig. 7.

densed in the pipe *H*. This pipe is slightly inclined toward the boiler, so that all the water which reaches it flows on to the boiler. The theory of this action is, that the weight of the water in pipe *I* is always enough greater than that of the detached plugs in pipe *G* to more than make up for the difference between the pressures at *L* and *F*, and so flows into the boiler against its pressure. The steam which separates the plugs of water in pipe *G*, and thus makes them collectively lighter than the water in pipe *I*, disappears by condensation in pipe *H*; and thus the action becomes continuous. The only office of check valve *L* appears to be, to prevent the water in the boiler from blowing off when valve *O* is opened to blow through.

The explanation seems reasonable, and the apparatus is said to be rapidly coming into use; but its action is so contrary to what would at first glance be expected, that I thought it would be interesting to hear more about it from the possible experience of some one present.

Mr. Emery.—There is no doubt but that the steam loop operates satisfactorily. It is practically a simple, and an inverted siphon ; the latter connected to the place to be drained, the former provided with a long pipe or condensing tube at the top. As water collects in the inverted siphon the steam in the regular siphon partially condenses, and the water in the former is carried up into the horizontal pipe of the latter to supply the vacuum, and running down gradually fills up the portion corresponding to the long leg, in due time accumulating sufficient head in connection with the pressure, to raise the check valve and enter the boiler. A continual series of partial condensations and restorations of pressure, carry the water from the inverted siphon over into the long leg of the simple siphon, and the apparatus works reliably when once started. I have used the same principle in draining steam mains in New York. Where it was impracticable to put a trap below the mains, I erected it in a box under the edge of the sidewalk. The water was lifted to the trap in the same way as in the steam loop, and when sufficient was brought up to fill the bucket, the trap valve opened and the pressure blew it out to the return main. You will observe one of these boxes in the sidewalk on Wall street, near Nassau street, and nearly in front of the Sub-Treasury building.

Mr. Worthen.—This reminds me of an experience I had. I was building a machine shop and put steam-engines on every floor and exhausted into a single pipe. The steam condensed and did not blow out except in clots. The exhaust pipe was 6 inches in diameter, and large enough for the engines, but the condensed water clogged in the pipe till the obstruction was so great that it was blown out with great force and in pails-full.

Mr. Emery.—I had the same difficulty with a steam-pipe working under considerable pressure. The 10-inch main on Madison avenue from 58th street north, ran up a rather stiff grade, sufficient it was supposed to

carry the water of condensation in the pipe, back under the current of steam moving up the hill to a trap at the foot of the hill. In practice, however, at least with but few buildings connected on the line and in the side streets, the current of steam up the hill was sufficient to hold back the water, and in some of the houses near the end of the line there would be a flow of steam for a time, when suddenly the whole system would become surcharged with water, until the pipe was drained at the top of the hill instead of the bottom. The difficulty was prevented by putting in two traps at different points along the slope, which delivered to the return main any water brought to them down the hill by gravity, or up the hill by the entraining action of the steam, thus preventing sufficient accumulations to form a plug of water to be carried into the buildings.

The CHAIR.—I understood Mr. Worthen to say he had made a great many connections from the street into the houses, by forcing the pipes through.

Mr. WORTHEN.—I did not say a great many, I said I had made them. Some steam heating companies make those connections now. At one time I had a boiler in Catharine lane, and my steam pipes were in the cellar, inside of the building into which I dug down to get room enough for the steam heater; then I had to get the steam into it and return the water. I took a piece of southern pine and made a box of about 4 inches inside diameter. I think I made it in two pieces. I laid it down and put a jack-screw behind it and had a spoon with which I removed the sand from the interior, and thus forced the box through, passing entirely under the foundation walls. It has been done a great many times since in that way without disturbing paving or roadway.

Mr. EMERY.—The first steam pipes I laid in the City of New York were carried across the street to the office of the company in substantially the way indicated. A 5-inch iron pipe was, however, used to form a conduit, being forced in from one vault by jack-screws, occasionally taking a scoop like a post auger to clear out the earth and sand that accumulated inside the pipe. Within the 5-inch pipe, two smaller pipes covered with felt were placed, to conduct the steam to, and bring back the return water from, the heating coils in our office building.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

468.

(Vol. XXIV.—March, 1891.)

THE USE OF ASPHALTUM IN BUILDING SEA WALLS.

By W. C. AMBROSE, M. Am. Soc. C. E.

WITH DISCUSSION.

The Ventura Division of the Southern Pacific Railroad is built for several miles along the bluffs facing the Pacific Ocean. The material of these bluffs is sand and gravel between strata of soft rock soluble in water; and though the violence of the waves is moderated by a group of islands about 22 miles off shore, at high water of spring tides with southwest gales they wash away the bank very rapidly, and protection for the road in some places was soon found necessary. The sea-shore at the foot of these bluffs is generally covered 2 or 3 feet deep with boulders and sand over the hard bed rock—hence the use of piling was impracticable. The rise and fall of tides, which would interfere very much with the work of building a concrete wall, as well as the high cost of labor, would make such a wall very expensive, so it was decided to try the use of asphaltum for a mortar to hold the boulders together, as a wall made of boulders alone had been easily knocked down by the waves.

At various points near this part of the road there are beds of material

known as bituminous rock, and asphaltum. The first contains fixed bitumen, 24.4 per cent., and ash, 75.6 per cent.; the ash consisting of silica, 46.8 per cent., carbonate of lime, 9.1 per cent., oxides of iron and alumina, 15.9 per cent., and other ingredients, 3.8 per cent. This material is much used in California in making pavements, and in coating piles to resist the teredo, which it does effectually. In order to liquefy it when heated, coal tar or crude oil must be added. About 200 feet of wall was built with this material, and it has stood perfectly for the last three years and prevented any washing away of the bank. After building this section of wall, the other material, known as asphaltum, was tried because it was cheaper. It liquefies without the addition of any flux, and when cooled it is not quite so hard but more elastic, and on the whole as good a cement as the other. It is often used for lining cisterns, and was used for 800 feet of this wall.

The wall was made 6 feet wide at the bottom (where it was in contact with the bed rock), 2 feet wide on top, and 9 feet high, the landward side, which was built close up against the cliff, being vertical. To economize asphaltum, only one half the wall, viz.: two feet backward from the seaward face, was cemented. The cost was $3.75 per cubic yard, which included everything except the old ties for fuel, and rail-transportation 28 miles for the asphaltum. In building this wall a layer of stones was placed, and the melted asphaltum poured over it so as to thoroughly fill all interstices and run down to adhere to the next layer of asphaltum. In warm weather the asphaltum becomes quite soft, but not liquid, and in this condition has little tensile strength, but the first spray from the waves hardens it just when necessary. The only part of the wall which failed was a short section where, to improve the alignment, it was built a little outside the base of bank, the space between being filled with sand. During a heavy storm, waves dashed over the top of the wall and saturated the sand, and the resulting increase in thrust from behind, pushed the wall over. This of course could have been avoided by making the wall so high that spray could not fly over it, or by increasing the width of base to resist pressure from the land side.

The writer thinks that when asphaltum can be had at a cost less than $10 a ton, this will be found a cheap sea wall. The stones on the beach, which because of their smallness and smoothness are of little or no use for ordinary rip-rap, can by this means be utilized, and are generally to be found in any required quantity on the spot.

DISCUSSION.

Mr. E. H. Wootton.—The question of using asphalt in masonry is not a new one; it has been tried for many years in Europe and there were some large blocks of asphaltic concrete placed at the mouth of the Gironde in 1865. I have made large blocks of asphaltic masonry here somewhat in the manner described by Mr. Ambrose; that is by taking the rock asphalt mastic pure, putting on a layer of stone, then another of asphalt, and then stone, and so on until the block is made. This solves simply and absolutely, the question of vibration in the matter of machinery foundations. Rock asphalt in large masses will not soften under any temperature. I have used it in this city in that way; the foundations of the two Edison 150 horse-power engines and eight dynamos, of the American Museum of Natural History, are of asphaltic masonry.

About the California asphalt I know very little. I saw the other day a piece of it at Dearborn street, in Chicago, and did not like it for street pavements. It is said to do very well on the Pacific Coast. I do not think there is the slightest question as to the desirability of the use of asphalt in sea walls; but the expense of using European rock asphalts would be very great. In small quantities it would cost about $50 a cubic meter, which might be prohibitive in any large sea walls. It might be made cheaper in large quantities, say $30. Whether the tars can be used to advantage in masonry, I do not know. In connection with French rock asphalts, I know they cannot; I should like very much to see true rock asphaltic masonry tried here on a large scale; of course water could not in any way affect asphalts, nor, in large masses, could heat. If not properly made it will soften under intense heat, but otherwise it will not.

The Secretary.—The point that occurs to very many is that there might be many points where ordinary coal tar would be a very useful material for cementing walls. I think Mr. Wootton hinted at that in his remarks. Of course, we know that coal tar will not last very long, but it is a cheaper material and might be used very effectively in some places.

The Chair, A. Fteley, Vice-President.—Does Mr. Wootton think coal tar could be advantageously used in such cases?

Mr. Wootton.—I know very little about the use of coal tar. The rock asphalts of Europe are bituminous limestones, containing about 10 per cent. of bitumen to 90 per cent. of lime (carbonate of lime). The asphalts, so called, used here, are different; the value of the hydrocarbon is a most important factor, and the sand mixture with Trindad bitumen I do not like as well as the limestone impregnated naturally. The use of European asphalts would certainly be much more expensive

than coal tar, Trindad, or California bitumens. With rock asphalt in masonry, vibration is impossible; it has been in use in Paris for such purposes about fifteen years; but this question of vibration seems to me to have little to do with the sea wall subject under discussion.

F. V. Greene, M. Am. Soc. C. E.—The objection to coal tar, for use in paving or any similar purpose, is its loss of strength by oxidation. The outside edge of it gradually wears away, the oil evaporates, and it loses its coherence. I think in large masses the coal tar would be comparatively durable, because the loss of the oils is from the outside, and is comparatively gradual. There have been a great many uses for coal tar in connection with paving, and whenever the tar has been kept from exposure to the atmosphere it has been successful; wherever used as a wearing surface, it has not.

There have been so many uses for tar developed in the last twenty years that the price has considerably increased. Refined tar is now worth about $17 to $18 a ton in this part of the country, and $18 to $20 in the interior. This California asphalt is much cheaper if they can get it. I think Mr. Wooton has covered almost all the cases for the use of asphalt masonry; almost all of them have been in Europe. The only case I know of in New York was an instance about two years ago. At the request of Tiffany & Company we built a foundation which was substantially a piece of asphaltic concrete, for a light trip-hammer in their factory on Prince street. For its construction I would refer to the following letter from J. W. Howard, C. E., who had charge of the work.

Captain F. V. Greene,
New York:

Dear Sir,—In answer to your request for information touching the Tiffany asphalt concrete foundation for their steam and drop-hammers, I send you the following data, from which you can select that which you may deem best. The asphaltic concrete block is 35 feet 8 inches long x 6 feet wide, x 4 feet deep. Upon it are placed seven large granite parallelopipedon blocks 2 feet thick. The seven blocks just cover the upper surface of the pier or asphalt concrete foundation. Each block just touches the next one. Each block is for the "anvil" of a separate "drop" or a steam hammer. There are four drop hammers, which strike a very sharp and following blow, and one steam hammer. The drop hammers are from, say, ½ to 1 ton each, and the steam hammers adjustable to perhaps above 3 tons. These hammers are used *ad libitum*, one or more at a time.

The asphalt concrete foundation is incased in a hard-pine box, held together by about 20 half-inch rods. The top of the granite capstones is level with the floor; thus the top of the asphalt concrete foundation is 2 feet below the floor, and the bottom is at 6 feet below the floor. The pier or foundation stands in a special room which was formed by the area or

yard of the building. The object in placing it there and in using asphaltic concrete, was to avoid the serious injury to the building, occasioned by the former foundations of the separate hammers, which occurred at several places in the basement; also to get rid of the jar so fatal to certain fine work on metal and glass, done in the upper portions of the building; also to make the place a pleasanter one to work and think in, for the employees. The foundation stands with its box free from the surrounding retaining wall, built for the purpose, 18 feet thick of brick. The cost of the "concrete," complete, was a very little less than $20 per cubic yard, but the cost of the wooden box and retaining wall being about $125, made the cost of the whole work, say, $24 per cubic yard (not including the granite or brick).

We tried the mixture which you indicated at first (with orders for me to change it until a proper mixture was obtained).

The first trial was with:

Asphaltic cement, 1 part		14½ per cent.
Sand, 2 parts	28¼ per cent.	
Broken stone (½-inch size), 4 parts	57¼ "	
		85½ per cent.
		100

This was too "rich," as it made a mastic. I tried in this mixture to get as close as possible to the consistency of the mixture I had seen used in France; and after using one load of it, we found the right mixture to be the following: Asphaltic cement, 9 to 8 per cent.; sand, 39 to 40 per cent.; stone, 52 per cent. A little limestone dust was used to secure a "dry" mixture which would retain its form at the average temperature of the place where the foundation was placed.

The mixture used as a final result was:

Asphaltic cement,	70 pounds	8½ per cent.
Limestone dust,	50 "	6½ "
Sand,	300 "	36 "
Crushed limestone,	400 "	49 "
Total,	820 "	100 "

This was laid up in 4-inch layers and tamped. We could not properly compress 6-inch layers.

Yours sincerely,

J W. HOWARD.

The CHAIR.—When you speak of tar as being successfully used when not exposed to the atmosphere, what do you mean?

Captain GREENE.—The bitumen foundations for pavements have been very successful. The work on the Manhattan Bridge was made of hydraulic concrete and granite blocks, making a double thickness of 17 inches.

Mr. THEODORE COOPER, M. Am. Soc. C. E.—I do not question the great benefit of asphaltic concrete foundations for machinery or for similar purposes, but I think the article described in the paper could hardly be classed as asphaltic concrete. It was, as I understand the paper, rock or boulders bound together with asphaltic cement to form a wall. The purpose of this wall was to resist the action of the sea in cutting away the embankment. The action of the sea upon a wall of that kind can only be of two kinds; if the wall remains a monolith the sea can overturn it or displace it as a mass; the other action of the sea is to disintegrate the wall. A wall formed of round boulders would be disintegrated very rapidly by the action of the sea, if cemented together with any of our ordinary mortars. Now, instead of using an easily broken mortar, which a Portland cement would be under the impact of a wave striking each joint, the author has used a plastic mortar, which is not acted on in that way. In this case it was an asphaltic mortar. The asphalt did not make the wall as a whole any stronger than Portland cement would have done; but I am satisfied that the reason he could not make a wall to stand with anything but plastic cement, was the disintegration of the cement mortar joints by the action of the sea.

EDWARD P. NORTH, M. Am. Soc. C. E.—The idea just touched upon by Mr. Wootton might, I think, receive further development; that is, the varying tenacity of different bitumens. There is a great deal of difference in the various qualities of bitumens; that from Trinidad is one of the most plastic of all. Those from Venezuela, Cuba, and Mexico, have in general less plasticity. The bituminous sand rocks found in California are all said to differ in quality; that used for street paving at San Diego, Mr. Schuyler, Member of the Society, writes to me, has its wearing qualities improved by the addition of from 10 to 15 per cent. of carbonate of lime, and must be about as soft as "refined Trinidad."

Specimens of sand rock from Kentucky. seem to be impregnated with a bitumen which is decidedly harder than that obtained from Trinidad, a circumstance which may or may not make it a better wearing material. In the European asphalts the lime rock is in most cases impregnated with a plastic bitumen, and in some the bitumen is so plastic and lacking in tenacity that it is impossible to use the asphalt in compressed work, for pavements, though such asphalts may make very good mastics.

I do not know that any one, before Mr. Wootton, has called attention to the variations in the quality of bitumens from different localities, or pointed out the fact that all bitumens are not equally available.

A. J. FRITH, M. Am. Soc. C. E.—Quite lately I heard of an instance which may be of interest in connection with this question of the use of

asphaltic concrete as a foundation for engines. My information is entirely hearsay. It seems that there were two establishments, in one of which there were a number of trip-hammers used, and in the other there was carried on a certain amount of engraving. The engraving concern complained that the jar from the trip-hammers interfered with their work, and for a long time it was considered that it would be necessary for the trip-hammer establishment to move away. However, the difficulty was gotten over by the use of asphaltic concrete as a foundation for the trip-hammers. This was entirely successful; and after it had been put in, there was no annoyance from the jar.

Captain F. V. Greene.—I think the gentleman refers to a well-known case in Paris. Mr. Wootton can give us information about it. I do not think it was trip-hammers that were in use, but very heavy machinery in one house, and the engraver in the other.

Mr. Wootton.—It was at the Seyssel works. In the works there we have a crusher, and there was an engraver in glass who lived near by, who obtained an injunction restraining us from the use of our crusher. It was then decided that this asphaltic concrete might remedy the trouble. We put the crusher on the asphaltic masonry, and there is now not the slightest noise. The matter of the trip-hammers, I think, occurred at other works where the rock as it comes from the mine is crushed and ground, and the introduction of asphalt masonry was successful in the same way; those are the two cases, I think. In the case of the Seyssel works the change was made in 1878, and there has been no complaint since.

Mr. Ambrose (closing the discussion) writes: Messrs. Wootton and Cooper have well explained an advantage possessed by asphalt over concrete in its plasticity and want of vibration under a blow. Another decided advantage in California is its comparative cheapness, as nearly all the best cement here comes from England.

Mr. Arthur Brown, Superintendent of Bridges and Buildings for the Southern Pacific Company used asphalt in building the foundations of the mansions belonging to Senator Stanford, the late Chas. Crocker, and the late Mark Hopkins, on what is generally known as Nob Hill, in San Francisco, and he tells me he found it very effective in preventing moisture of the soil from getting into the walls, as it is thoroughly non-absorbent of water.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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(Vol. XXIV.—March, 1891.)

A COFFER DAM OR CAISSON WITHOUT TIMBER OR IRON IN ITS CONSTRUCTION.

By ROBERT L. HARRIS, M. Am. Soc. C. E.

WITH DISCUSSION.

During the winter of 1888–89 the New York and Northern Railway Company determined to replace the iron bridge crossing Croton Lake with a heavier structure, one more in accordance with modern standards, to carry the rolling loads of the present day, and the writer was called upon to attend to the matter.

The masonry work in connection therewith developed what all may wish was a peculiar state of affairs, to the extent that what appeared a simple matter became one of anxiety, watchfulness and extreme care; its difficulties required special efforts, and were overcome by an original mode which may interest members of the American Society of Civil Engineers and the profession.

In order to make the matter clear, it is necessary to have a long preface to a short story.

The bridge existing in 1888 was a single track, wrought-iron deck structure of three spans of 150 feet each; total length, including cross-

ings of iron towers, about 480 feet; depth of trusses, center to center, 24 feet; width from center to center of trusses, 13 feet. These spans rested upon skeleton rolled-iron towers, 41 feet 7 inches high, each consisting of four columns properly tied and braced (24 feet 3 inches x 16 feet 8 inches between centers of base plates). The base plates rested upon granite blocks 12 inches thick and about 6 x 5½ feet in area, at the corners of bases of masonry, so called, 32 x 22 feet in area, about 7 feet thick, built upon cribs 47 x 35 feet, with nine compartments filled with stone. The cribs are represented on an original drawing as composed of 4-inch plank, laid cob-fashion, gained and bolted together; and around the cribs had been placed some rip-rap. The depth of water at the southerly crib is about 18 feet, at the northerly crib about 28 feet. The cribs and masonry bases were built about the year 1869 by the New York, Boston and Montreal Railroad Company, which company failed just before an iron bridge was to have been erected there. In the year 1879 the deck bridge mentioned was erected by Mr. A. P. Boller, M. Am. Soc. C. E., and did good service until its removal in 1889.

The masonry did not awaken suspicion upon preliminary examination, especially as it was old masonry, fully pointed (but some stones "quakered"), upon crib foundations that had been in place under water twenty years. It was therefore judged that all which would be necessary would be to add more rip-rap outside the cribs, and build piers of masonry within the skeleton towers upon the old masonry bases, increasing the lengths of spans to conform therewith. The weight upon the bed-plates of the skeleton towers at tops of stone bases had been over 17 tons per square foot; the weight of the proposed structure and its extreme load applied within the area of the skeleton towers at top of the bases would be under 3 tons per square foot, which by good arrangement, and including weight of base, could be delivered at the crib at less than 2½ tons per square foot.

As is usual in railway work, when anything is wanted, it is essential to have it quickly. Proper measurements were made, designs prepared, and contracts let for three heavy iron spans, and for two masonry piers upon the old masonry bases.

On the first day that workmen appeared (in February, 1889), holes were ordered drilled through the masonry bases at various designated points, with instructions to drill at least 6 feet, for the purposes of

thorough examination and of filling any possible voids with grout. The covering stones were large, well-bonded and apparently good. A gang of drillers began in the morning of a very cold day, and our painful surprise may be conjectured when these men were found at the blacksmith's fire in about an hour, and reported that the first hole, 2 inches in diameter, was completed! "We want the hole 6 feet deep at least." "It is down as far as our drills will go; we drilled 8 or 10 inches through the stone, then the drill went nearly of itself much of the rest of the way, except when bound for a few minutes." Other holes were tried with similar results. Some of the covering stones were then racked off, and I hope never again to see such rascally work where solidity is expected. The thin roof and sides were but a shell, enclosing large and small stones, boulders, posts, sticks, dirt, some sand, but no cement; even the joints of cover and wall stones had barrel staves and pieces of wood so placed as to prevent mortar from working into the main base. It was a loose mass, as though stone-boats and dirt-carts had been promiscuously used to "dump" in anything that would fill up.

My agreement, and also the contract of the masons, Messrs. Hodge & Miner, was only from above these masonry (?) bases. My inclinations were to abandon the work, but the president of the railway was absent at the West. At this time a friendly act was performed by a brother engineer whom I then slightly knew. A friend told me that Mr. A. P. Boller, M. Am. Soc. C. E., would like to see me; upon promptly visiting him, he unreservedly told me of his experience in 1879 at the same place, and handed me a copy of the *Transactions* Am. Soc. C. E., for April, 1882—very interesting reading to me at such a time!—and in which he related the ingenious manner in which he surmounted a difficulty that was presented to him.

The following quotation may be more agreeable to my audience:

"Before closing this brief account of a temporary construction, the disclosures of these old piers is a story worth telling, and of all deliberate, studied, cold-blooded frauds, those piers are entitled to the highest rank, and should consign to infamy all parties concerned in their creation. They were nothing but the merest veneer of stones set up on edge, with no cement detectable internally, and filled up with sand, stones and rubbish, an occasional barrel-head, and a plentiful supply of engineers' stakes, to 'level up with.' Many of the coping

stones were actually cut cross-grained, and no expense was apparently spared in doing anything wrong. Such instances of cold-blooded criminality almost restore any waning faith one may have in a hot immortality."

At the close of our interview he told me I could rely on the masonry corners, which he had rebuilt upward from the crib.

An entirely new phase of affairs had presented itself. It was decided, however, concurrently with the president, a member of this society, as the iron spans were now being built, and as the corner compartments of the cribs had carried the old weights so many years, to continue on the general plan, and begin the new work from near the crib, it being judged that a distribution of the increased weight over so large an area of the crib as possible would be sufficient.

The first thing necessary was to re-enforce the cribs for the changed application and increase of the weights to be borne. A mass of rip-rap having a berme of 7 to 10 feet at the top of the crib and a slope of one and a quarter to one, was placed around each crib.

Time had shown that Mr. Boller and Mr. Sebastian Wimmer, M. Am. Soc. C. E., were right in considering the corner compartments of the cribs sufficient for their purpose; they however, had the advantage of a summer season of very low water for their construction, while with us it was winter and early spring, the water icy cold, and Croton Lake at an ordinary level, with prospect of higher water. The Chief Engineer of the Croton Aqueduct informed me that the lake could not be lowered by reason of the scant water supply of New York City, nor would it be materially lower during the summer, which proved to be the case. The tops of the cribs were about 7 feet below the top of the bases, or only about 5 feet below water, just sufficient to reqnire diving appliances or a coffer dam or caisson of some kind, to remove the interiors of the bases with extreme care. We removed all of the middle that we dared, by hand, chains, and grapples, but the water was too muddy to permit of careful work at the sides, ends or corners. The bottom of the lake was irregular and with many boulders; the old rip-rap, though scant, was spread out, and we had been obliged to place the new rip-rap before interfering with the bases.

Various expedients were considered and rejected; such as forcing sheet-piling through the rip-rap, covering the entire surface of the rip-rap with tarpaulin, etc. Upon reflection a plausible resource presented

itself, which further thought convinced me was feasible, and this seemed *the* place to try the experiment. We wanted a tight bottom at any level below the top of the crib, and tight sides thence to the water surface. The idea was to use the materials that were in place, and make a caisson therein without disturbance, by *cementing*, for the floor of the caisson, a portion of the loose mass of irregular stone-filling in the crib at any level below the top of the crib; and for walls, to cement from thence to the water surface, or as high as necessary to make good connection with the shell; this could then be pumped out, the interior carefully excavated to the crib, and the space filled with concrete rammed in layers to the top of the old shell. I spoke with several engineering and contracting friends on the subject. None had ever seen it done, only one (a Canadian contractor) expressed any confidence in the success of the trial.

The track upon the bridge was over 75 feet above the crib, and grout could be mixed upon the track over the crib and delivered directly through a hopper, pipe and nozzle; this was done, but the plan was soon changed to pumping in the grout immediately at the base. Holes were pushed and worked among the stones until a few feet below the top of the crib; these were held open until required, by crowbars, pipes, poles, etc. A long nozzle of 1½-inch iron pipe, connected to the discharge pipe of a No. 2 Douglas hand force-pump, was inserted in one of these holes to its bottom, water was rapidly pumped through for a few minutes, then the suction hose was suddenly transferred to a reservoir of grout, composed of Alsen Portland cement and fine sharp sand, in equal parts, mixed immediately before use; a small quantity only of the grout was slowly forced through, and the nozzle was then withdrawn but the hole maintained, and the same operation was proceeded with at other holes, seldom returning to any hole on the same day; my belief being, that in quiet water the cement would accrete on the surface of irregular stones at and below the level of injection, and that by consecutive slight accretions at proper intervals of time the voids between them would be filled.

I had tried an Edwards centrifugal steam-pump of 6-inch discharge to free from water the excavation made by the men who were working in rubber clothing, but with no avail; the immense sieve had too many and too coarse meshes. After repeating the above-mentioned operations for many days, with trials of the 6-inch steam-pump once in a while, ap-

parently with no success, I was on the point of abandoning the idea, of believing others' opinions in preference to my own judgment, when upon a Monday morning trial, after a quiet setting of thirty-six hours, the steam-pump, to my satisfaction, lowered the water a few inches; this assured me of success, and after patient continuance of grout injections a few days more, we pumped the space dry in a few minutes. We then proceeded with the excavation to the crib with so little water that at times a single man at the hand pump kept it free, and finally succeeded in putting in very rich béton, composed of Alsen cement 1, coarse sharp sand 1, broken rock 4, in solidly rammed layers of 9 inches thickness. During the excavation we found, at 6 feet away from the nearest nozzle holes, sharp-edged stones upon whose acute angles there were accretions of cement over ½ inch thick.

I had made a cemented caisson or coffer dam, in water, at a short depth below the top of the crib, using the loose stones there in place; and it is well to state that close observation during the operations failed to show loss of cement into the lake through the outside of the rip-rap; this is accounted for by the care exercised in forcing slowly but a little grout at a time at any one hole, and in giving it time to accrete upon the near rocks before another charge was applied.

We had obtained such success at the one pier in 18 feet depth of water that we adopted the plan (improved) at the other pier in 28 feet of water without serious trouble, and a heavy load of anxiety was lifted when solidly rammed Portland cement concrete filled these bases to the height of the walls of mere shell of the old "masonry" (?) bases, for, during all the time, trains were running regularly, though at low speed, over the spans resting on the iron legs supported by the four almost isolated corners of masonry.

Upon the concrete filling were reared the new piers, a little over 40 feet in height, the bases of which were about 22 feet 10 inches x 15 feet 4 inches, each narrowing at 8½ feet to a shaft whose base is 20 feet 7 inches x 9 feet 3 inches, and the top under coping 18 x 6 feet 9 inches, surmounted by coping 19 x 7 feet 6 inches, 18 inches thick. These support three deck spans of 156 feet 9 inches, center to center; depth of trusses, center to center, 25 feet 4 inches (total height from base of bed plate to base of rail, 27 feet 11 inches). The trusses are 13 feet between centers. These spans were designed by Theodore Cooper, M. Am. Soc. C. E., and were manufactured and erected by the Passaic Rolling Mill Company, of Paterson, N. J.

The process can be successfully used with rip-rap or rubble, and can be applied also to coarse gravel, gravel, sand, and even quicksand by the use of proper precautions. It affords a simple and convenient mode of making coffer dams, caissons, breakwaters, shore protections, etc., using largely the materials at hand or in place, instead of cumbersome structures for which all the material must be transported; especially is it useful in enlarging, repairing and strengthening sub-aqueous structures, while it may also be used in solidifying some kinds of materials for subterraneous structures, as tunnels, shafts, etc., and the enlarging of bases for foundations upon unstable materials.

In conclusion, I wish to emphasize the fact that this was not a work of choice; but necessity compelled the use of the old foundations, and it was required to accept the conditions as found, and to do the best possible with them and under the circumstances.

DISCUSSION.

Charles Macdonald, M. Am. Soc. C. E.—It would appear that the work described by the author, and illustrated upon the screen, is the familiar experience of a masonry pier founded upon broken stone enclosed in a timber crib, partially surrounded with rip-rap. Foundations of this kind have been successfully used in many parts of this country (where there was no tendency to scour), without involving the expense of injecting cement mortar through the upper layers, and it is difficult to understand the object of departing from previous practice in the present case. The late Mr. Fred Mercur constructed several piers in 40 feet of water on the Lehigh River, by sinking cribs and filling with broken stone, upon which masonry was started a short distance below water level. In one case the crib in sinking came in contact with an old canal boat which lay diagonally across the axis of the pier. Time was short, and to remove the canal boat would have been a very serious matter, so it was decided to dump broken stone through the crib and around the outside until a suitable bearing for the masonry was reached. In the construction of all these piers there was, no doubt, more or less settlement, as the weight of masonry was added, but all necessary compensation was provided in the finishing courses. I adopted this method, although in much shallower water, in founding three piers in the Schuylkill River. Every new course of masonry

Note.—It is proper to state that the mode described in this paper was patented in 1890.
R. L. H.

Fig. 1.

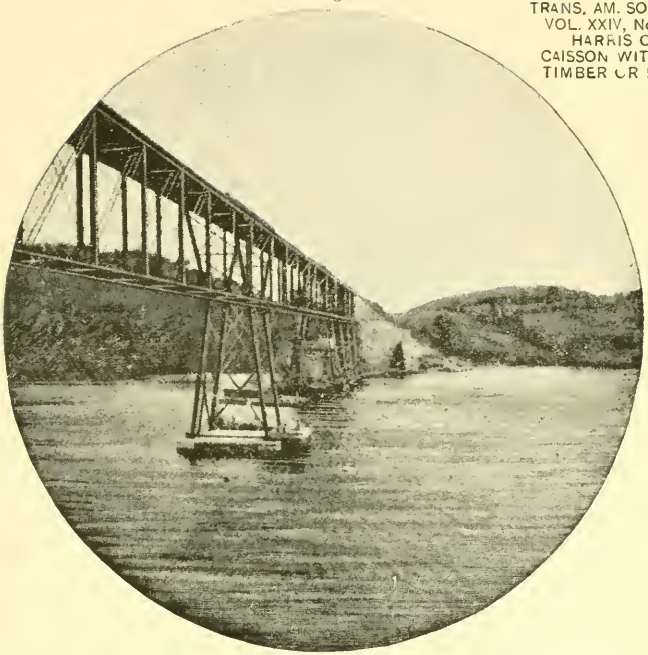


Figure 1 is a view of Croton Lake Bridge upon iron towers, as it was previous to 1889, and before the northerly pier was begun.

Fig. 2

Figure 2 is a view of the old spans still on iron towers, but both masonry piers are built.

Fig. 3.

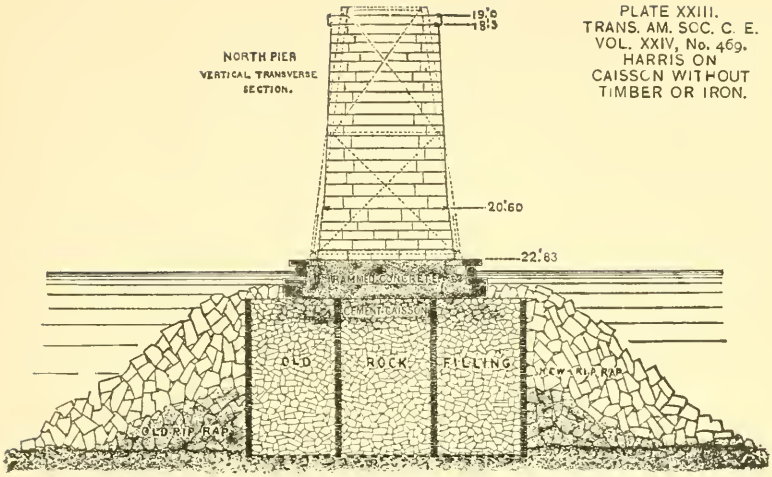


Figure 3 is a vertical transverse section of the northerly pier.

Fig. 4.

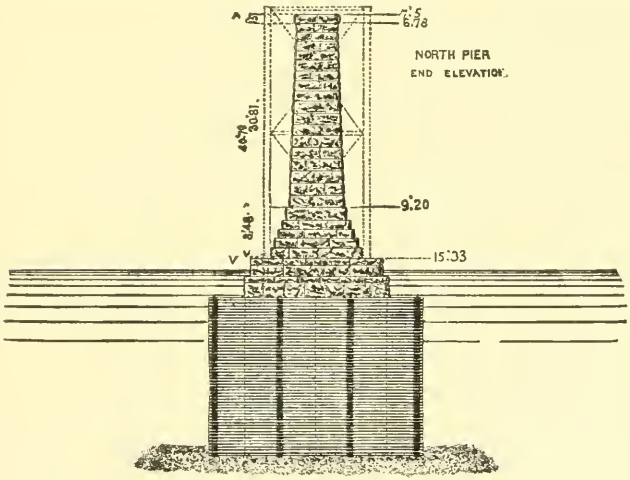
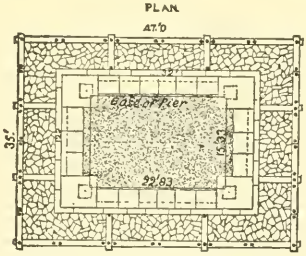


Fig. 5



Figures 4 and 5 are respectively an end elevation and a plan of the northerly pier.

Fig. 6.

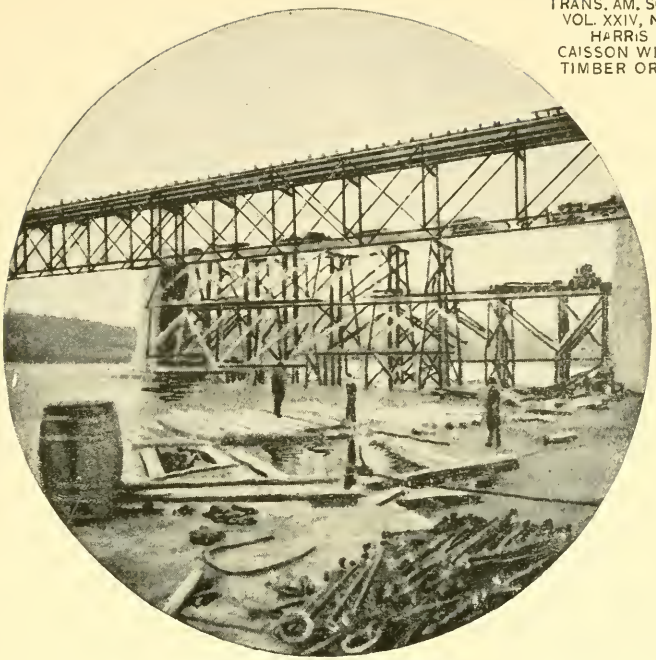


Figure 6 is a view of the completed northerly pier with two of the new spans resting thereon, and a portion of the false work.

Fig. 7.

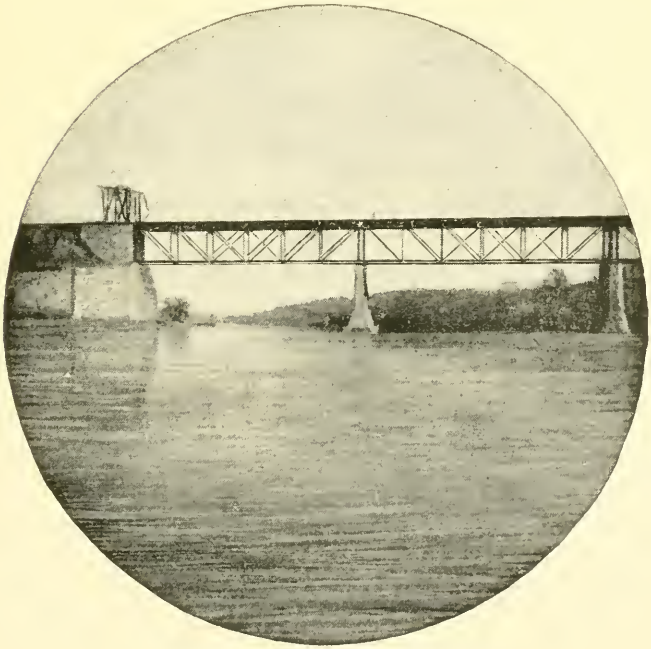


Figure 7 is a view of the completed work.

caused a slight settlement, sometimes canting the pier out of line, but by paying proper attention to the levels from day to day the work was finished up substantially as required, and there has never been any disturbance since. I do not wish to be understood as advocating broken stone foundations in opposition to rock in place, or other equally suitable foundation. The instances above mentioned are given merely for the purpose of showing that such foundations may be relied upon under certain circumstances, if properly handled, and that the injection of cement mortar through the upper portion of the broken stone cannot, from the nature of the case, alter or improve the character of the support beneath.

J. Foster Flagg, M. Am. Soc. C. E.—Mr. Harris has clearly described how the bottom of his caisson was made tight, by the injection of grout between the interstices of the loose rock, but I do not understand how he formed the walls of his caisson. Was the masonry of the outer skin of the pier laid well enough to answer this purpose and prevent the passage of water, or was the same process pursued for making the walls water-tight as for the bottom? If the existing masonry was depended upon for this purpose, how thick was it necessary to leave it in excavating the caisson for the new concrete foundation?

T. C. Clarke, M. Am. Soc. C. E.—How deep did you go under the water?

R. L. Harris, M. Am. Soc. C. E.—I wanted to get to the crib, the top of which was only about 5 feet below ordinary water surface, while the water was about 28 feet deep. The means I adopted to make a cement floor for the caisson was to force cement through pipes which reached a few feet below the top of the crib.

Mr. Clarke.—You actually got under the water 5 feet?

Mr. Harris.—The top of my floor was about 5 feet under water, but my operations of floor-making were mostly below this depth. I wanted to remove the poor material down to the crib. In reply to Mr. Flagg's question: The top of my newly-constructed floor was nearly at the top of the crib; the space between the floor and the shell of the old base was filled with injected grout, forming walls; we used sand bags and cement bags to aid in making the joint, and also in making tight the shell composed of the old stones.

Mr. Clarke.—How thick were they?

Mr. Harris.—The old walls varied in thickness from 12 to 24 inches.

The Chair (A. Fteley, Vice-President Am. Soc. C. E).—Do I understand that on the gravel bottom of the lake you have a mass of rip-rap or dry stone without any cement, and that you have formed on the top of that pile of stone the capping of cemented masonry that you are speaking of? The ultimate base of the bridge is this capping, I understand.

Mr. Clarke.—This question of building on broken stone is a very

interesting one. My experience has been that, providing you get your foundation large enough and reduce the pressure per square foot sufficiently, there is no difficulty in doing it. The great difficulty is when we have a foundation in which the supporting power varies, where one part of it is not as hard as the other. Mr. Macdonald gave an illustration of building over an old canal boat; I once had to do the same thing. In one of the piers of the Girard Avenue Bridge at Philadelphia the foundation stands on an old canal boat. The piers are about 120 feet long and 20 feet wide at base, 10 wide on the top and 45 high; they rest upon cribs which are filled with concrete. The bed of the river is rock and was covered with 3 or 4 feet of material which had to be removed by dredge. When we began to dredge we found something in the way; we dredged off the clay, etc., so that the divers could get at it, and we found that there was an old canal boat sunk there, loaded, as the divers discovered, with pig-iron, and this boat lay diagonally across where I wanted to build my foundation. These cribs were about 130 feet long by 30 feet wide. I did not exactly know what to do, but as I had to do something, I designed my crib in such a way that it should stand right over this canal boat. I came to the conclusion if it was loaded with pig-iron it must have come to its bearings; so I dredged out each side and made a sort of saddle, and built the pier upon it, and there never was the slightest indication of settling.

The Chair.—In view of what has been said by Mr. Macdonald and Mr. Clarke, have you found in your practice, Mr. Harris, in erecting your pier on this foundation, any settlement, one way or the other, or have you observed the levels at all?

Mr. Harris.—There has been nothing extensive; of course, we naturally expect some settlement in work of the kind. I have had nothing to do with it for the past few months, but think it is all right. (It was built in 1889.) During the erection of my work there was some settlement, but not enough to result in trouble.

Mr. Macdonald.—The settlement I referred to occurred from day to day and was leveled up by the masons each morning when they came on and found that a course was not exactly level.

The Chair.—You speak of the difference of alignment as about 8 inches; I should say that that required considerable care in order to have straight arises.

A Member.—There was a decided difference in the two cases; in Mr. Macdonald's case the stone was thrown in just before building the pier; in Mr. Harris's case, they had been thrown in a long time before and had had time to settle, that would make a much better foundation.

John N. Ostrom, M. Am. Soc. C. E.—In reference to grouting in loose stone, I have had a little experience. A few years ago I was building some bridges in Texas and the Indian Territory. In several of the bridges the masonry was to be located on a concrete foundation. I

found in one case, after getting on the ground, that a young engineer who was in charge of the work, not knowing exactly how to make his concrete and not mixing it in the ordinary way, had made his excavation, filled it up with the proper amount of broken stone and then made a grout and ran it through. He had used about sixty barrels of cement in one small pier; the pier on the face of it, was about 10 x 30 feet. In that case the grout had permeated to the very bottom. There was a great deal more cement used than necessary. I do not understand in Mr. Harris's case why the grout did not go deeper, unless the broken stone was filled up with silt. I think if it had been put in when the broken stone was first deposited, and before the silt had permeated the pile, and if he had tried to form a thin caisson at the very top, he would have failed to the extent that he would have had to fill that whole mass of broken stone. I cannot understand it otherwise; I know in my case they used sixty barrels of cement in one small pier. I would ask how much cement was used? The question of cost, of filling a whole pier to the very bottom, would have been very serious.

George R. Hardy, M. Am. Soc. C. E.—As I understand it, there was considerable expense incurred for removing the central portion of the old work after the floor was made; and it occurs to me to ask whether you could not have continued the work, and concreted the entire mass without excavating inside of the cement coffer dam, having once established a box sufficiently water-tight to prevent the cement or concrete from escaping.

Mr. Harris.—The material I wanted above the crib was thoroughly rammed Portland béton; engineers know that can be depended upon. We could have a larger bearing-surface down in the crib by reason of the flowing of the cement to a short distance, thus resulting in a tight floor of considerable area. I obtained not only an extended floor, but also cemented sides, to my caisson, to carry the rammed béton that was introduced.

Charles E. Emery, M. Am. Soc. C. E.—While it appears that bridge-builders have different methods of arriving at a result, I think that the method adopted shows great originality and one which can be employed in other cases, for instance in tunnel work, in enlarging foundations, etc. Very great credit is due Mr. Harris for successfully carrying out a novel engineering work, even if it be not done in the same way that those who have used cribs for so many years would have done it. I have been very much interested and can see quite a number of applications. The method of grouting employed in the recent tunnel under the Thames for the South London Railway is familiar, but grouting in this case accomplished another purpose and made a coffer dam. The application of the grout in small quantities so as to form gradual accretions like those on foreign substances in mineral springs, is very interesting, and it is probable that the success in making a tight floor at the top of a pile of loose stone, is entirely due to the special method.

Charles B. Brush, M. Am. Soc. C. E.—I understand that Mr. Bogart is familiar with the rip-raps at Fortress Monroe; I would like very much to hear something about that construction.

John Bogart, M. Am. Soc. C. E.—The only point in connection with the very interesting paper of Mr. Harris is the fact that rip-rap foundation will hold itself in remarkably good shape, even after a very great settlement. The stone fort on the rip-raps was commenced in the early part of the century—probably about 1830. The rip-raps are nothing but an artificial island of stone on a sandy shoal which seemed to be very solid. The shoal was from 70 to 16 feet deep, and the island was made of broken stone of large size, brought from Maine and from the Richmond quarries, and thrown overboard from the vessels upon this rip-rap island. In 1861, this former fort which had been built up one tier of casemates was being loaded by order of the then Chief Engineer with a very large amount of granite, because it had shown some signs of settlement. The whole island settled, I should say something like 8 feet, and rather regularly. A new granite fort was commenced and was built during the years 1861–66, and no more settlement was observed up to the time that I left there in 1866, that was after five years; the island seemed to have reached a solid foundation. There was a layer of sand directly beneath the rip-rap, I do not know how thick, and there seemed to be a layer of some soft material under the sand which was pushed out into the sea.

Mr. Brush.—Did the rip-rap stand outside the fort?

Mr. Bogart.—Yes, all round outside the fort; a berme of 20 feet, and then it takes a slope of perhaps 1½ to 1 feet, running down in some places to 70 feet of water.

Mr. Brush.—What was the object of building that fort?

Mr. Bogart.—The object was in connection with Fort Monroe, which commands the channel to Norfolk and to Richmond.

J. Foster Flagg, M. Am. Soc. C. E.—Is not Fort Carroll, in Baltimore Harbor, built in the same way?

Mr. Bogart.—It is built on an island, and there was some settlement but nothing like this.

E. P. North, M. Am. Soc. C. E.—Is there any one here who knows how much loose rock, thrown in for foundation, will settle, that is, neglecting the settlement of the material it is resting on. I have never seen any statement that rock itself would settle more than about 4 or 5 per cent. of its thickness, when it is thrown in for foundation.

Mr. Emery.—Does not the old Croton Aqueduct, in some sense, answer that question? My recollection is it was built with retaining walls and filled in with dry stone.

Mr. Bogart.—I am very sure that in filling in with loose rock above water, with a very slight adjustment of the rock as it goes in, the settlement is very slight; I know from experience not to exceed 3 or 4 per cent.

The CHAIR.—Engineers who are building railroads have on many occasions to make use of rock taken from cuts; if there is anybody here who has any data in regard to that matter it would be a good answer to Mr. North's question. I understand that railroad engineers expect a certain amount of settlement.

Another question has been asked by Mr. Emery which I might answer, so far as my knowledge goes, of old matters that were not under my direction. It is a fact that the old Croton Aqueduct, which has been for so many years the main water supply of New York, wherever it is placed on high embankments, is built on a high wall made of dry stone, and the greatest trouble the engineers have experienced has come from that fact. Although those walls were built by placing the stones by hand, there is no question that the aqueduct has settled greatly, thus developing cracks; that water penetrating those cracks has reached the foundation, softened it and probably produced thereby a still greater settlement.

JAMES OWEN, M. Am. Soc. C. E.—Mr. Ashbel Welch stated that in making a rip-rap masonry wall 40 feet high, along a river bank, the settlement during construction was 4 inches.

Mr. HARRIS.—This discussion has turned in a way that I hoped it would not; perhaps we are discussing that "long preface" instead of the "short story;" we have been diverted from caissons and coffer dams to rip-rap and loose rock, and I would request members to discuss the subject of the evening. My paper is not in advocacy of rip-rap nor of broken rock foundations. I had hoped to listen to a discussion in regard to caissons and coffer dams, although what the gentlemen have said has proved very interesting. If you wish broken rock talk, perhaps one instance that has come under my observation in New Mexico will be of interest.

Within the past three weeks I have seen a rock-fill dam, 45 feet high, extreme length over 1,000 feet, its upper face made tight with earth. I looked at the outside of it; it was as dry as any masonry dam; it has not been finished over a year and a half. This was a case where the managers had sufficient confidence to build a broken rock dam, reported to have cost a couple of hundred thousand dollars, for very extensive irrigation works, and which would cause immense damage if it should give way.

WILLIAM E. WORTHEN, M. Am. Soc. C. E.—Under such conditions I should silt up the dam with sand.

Mr. HARRIS.—That is probably what really occurred.

Mr. NORTH.—If that dam was silted up with sand would it be as strong? Would not any water in the dam weaken it? Those rock dams are built tight on the upper side and perfectly open on the lower side, so that any water that does get in passes through it.

Mr. MACDONALD.—Might not that process of construction very well be applied to the Quaker Bridge dam?

The CHAIR.—I will for obvious reasons ask somebody else to answer that question.

I see, Mr. Harris, that you have been trying to bring the audience back to your paper, and have succeeded in making another diversion. I will try to assist you, if I can, by asking a question. You have, in your conclusions said that you thought such a process as you have resorted to would be very useful in foundations under water or in sliding masses of gravel. This is a subject on which there is very little known, and I would ask whether any one present has, in his experience, ever injected grout into a mass of gravel, or a mass of stone, or into a medium supporting a structure of any kind, and whether in so doing he has produced a foundation better prepared to support a heavy weight?

CLEMENS HERSCHEL, M. Am. Soc. C. E.—My sympathies have been with Mr. Harris to a great extent in having given us a paper on the injection of cement into broken stone, in his case for the purpose of forming a coffer dam, but the process could also be used to solidify masonry, either under or above water. The audience having gone off into other channels, and you having brought the subject back to the injection of cement into masonry or broken stone, I will cite a few instances of such work that was done under my charge.

The masonry about the works at Holyoke, Mass., were built in 1848. Like Mr. Bogart at Fort Monroe, I was not there when they built them, but about forty years after, for some unaccountable reason, it began to come to pieces. The stones were very large rocks and, of course, on that account there was no danger, so far as stability was concerned. Being in constant use, there was no such thing as making the repairs in the ordinary way; but on the fourth of July there are two or three days in every year when the water is drawn off, and we concluded to try boring and drilling holes beforehand through this masonry, very close together. Advantage was taken of these two or three days to pour cement through such holes into the masonry, and attempt to stop these leaks. That seemed to be the only thing that could be done under the circumstances, and we concluded to attempt it. The various classes of masonry were treated in that way, holes being drilled through, some 15 or 16 feet deep.

Mr. CLARKE.—How large ?

Mr. HERSCHEL.—About 2-inch holes. There are various kinds of masonry there, some large and some small stone, and some almost dry walls. We did this for two years; that is, it was only treated on two occasions, but the drilling occupied a very long time, and in most cases the success was very marked. Some walls that leaked like a sieve are now quite tight. This is a case of pouring cement somewhat similar to what Mr. Harris mentioned, only the masonry was a great deal more regular; it is another example of injecting cement in stone.

REUBEN SHIRREFFS, M. Am. Soc. C. E.—I can add another illustra-

tion of the same principle. Down on the James River there was a wooden bridge that was destroyed during the war. The piers were built of ordinary rough stone entirely dry. In course of time, some twenty-three or twenty-four years, I think, had elapsed before they were used again, the railroad company with whom I was at that time, undertook in conjunction with the town, to bridge the river with an iron bridge, and it was determined to use the old piers. We did it in much the same way as Mr. Herschel repaired his masonry. We pointed the outside joints very carefully for a height of about 5 feet perhaps, and when we could find a crack deep enough to insert an iron pipe we put it in and forced in the cement in that way. We had some repairing to do in some cases, but it worked admirably and the piers are solid, and it is hoped they will be for a good many years yet.

Mr. Harris.—Did you use a pump ?

Mr. Shirreffs.—No; we just used head. I do not remember now how much it took per cubic yard. In this connection I might cite the case of a coffer dam across the same river at Lynchburg, which I used in building a dam there. The rock bottom was completely bare; it was considerably laminated and there was no chance at all to hold an ordinary sheeting, so we built a crib of logs, filled it and sunk it with stone and then on the upper side we banked it with dirt and let the dirt be carried into the interstices of the stone; it made an admirable coffer dam.

Mr. Worthen.—A great many years ago I read of the French way of injecting under foundations; they drilled holes down and injected cement in that way. About 1845 I had to repair the foundations of a flume and did not want to dig it up; so I put holes along wherever it was unsound and made a syringe to inject the cement under the foundation. The pipe was a 6-inch pipe and went up about 3 feet high; that was bolted to the flume. I filled it with cement and then used a wooden follower in the pipe and rammed the grout down until it appeared at the next hole. The work has stood thoroughly well since.

In 1853 or 1854 we put a second track on the New Haven road at Westford. We had a draw pier and it was of very poor masonry. We drove piles outside of the pier and put in a stone wall laid in cement. The old wall was horrible, so I took it down as low as I could and put sand on the top and squirted in the cement. The pier is there to-day and doing good service. I think if you can once fairly silt up loose rock, it will be in most cases as durable with sand as with cement.

Mr. Harris.—In reply to Mr. Ostrom, I would say, that just before success was assured I began to fear that I might be obliged to fill the crib, or try some other plan. As a matter of special interest in this connection, an incident occurred immediately previous to the complete sealing of the floor, which indicated a great deal to me, but which generally would be of more value to naturalists than to engineers. A

sudden burst of water near the middle of the floor brought into the enclosure a lively eel, 1½ inches in diameter and nearly 2 feet long, which must have come from the outside through 20 to 25 feet of angular rip-rap and broken stone filling; its skin was not even scratched. The quantity of cement used was 101 and 134 barrels respectively for the two piers, mixed with equal bulks of sand. My caisson was a great deal cheaper than any other which could have been constructed.

In regard to the dam at Holyoke, I would ask Mr. Herschel whether the water was drawn down before the grout was put in?

Mr. Herschel.—The work was not done on a dam, but in canals, and they were dry. The grout filling was cement and water, no sand. I mentioned it as being nearly a parallel case. I think yours is the only case I ever heard of where the grouting was done under water.

Mr. Harris.—We have now heard of grouting in various ways; all of these are good instances of ordinary modes of applying grout. In this very neighborhood, upon our new Croton Aqueduct, we have ingenious examples of grouting still more striking.

I will go beyond these, to grouting under water. Since writing this paper, I have read, in current technical literature, of the exceedingly interesting experiments and practice of Mr. Walter Robert Kinipple, M. Inst. C. E., as described in reports of his late lectures on "Subaqueous Foundations." It is said in these reports, that Mr. Vernon Harcourt's work, on "Harbors and Docks," 1885, states: "The lower courses of the superstructure being laid below low water, cannot be cemented together." Mr. Kinipple's experiments of 1883 and 1884 were apparently made by sinking a box in which small broken stones were placed, and then filling the remainder of the capacity of the box with grout; as for instance, at Aberdeen "A very thick grout * * * * was poured down the pipe in sufficient quantity to fill up the whole of the interstices." He subsequently put these experiments to handsome use in the building of heavy sea walls, and in each instance cited he had, or formed, a bottom, and he formed sides for the retention of grout, as per the following extract in regard to the Hermitage Breakwater, about 1887: "It" (a section of rubble or shingle) "was enclosed by bags of concrete on three of its sides and made cement tight all round." What I wished to draw out from the gentleman was: do they know of any case where cement grouting has been carried on, under water, without there being beforehand a confining bottom, or confining walls, or both? do they know of any case where use has been made of the plan which I adopted? a plan which, if I mistake not, differs esentially from, and goes beyond, the various modes of grouting which have been spoken of this evening. My process is based largely upon the principle of successive accretions.

My idea was doubtless suggested by reason of some lime incrustations at a spring where I camped over twenty years ago, and where twigs

became encased during a single night; which experience I recollected six years ago, and which then rather astonished a young and blooming saleswoman of curiosities at Manitou, Colo., who had labored bewitchingly a long time to impress upon myself and family that a thousand years were required to incrust to the thickness of $\frac{1}{16}$ of an inch.

In the work described in my paper, my belief was, and the result sustained it, that a thin scale or film would be made on the rocks at the first injection of the grout; at the second injection an additional thin scale would accrete, and so on; thus not requiring either bottom or sides to confine the cement. In digging out some rocks after I had partly made the floor, I found a stone, with acute angular planes, on the sharp edge of which over half an inch of cement had accreted; this interested me deeply.

My belief is that my mode is different from ordinary grouting, that it is new, and also is an application of the principle of accretion, of adding little by little, similarly to the processes of nature.

H. W. Brinckerhoff, M. Am. Soc. C. E.—Did your observation show that the accretion was usually greater upon the edges than upon the sides of the stones; as, if this were the case, it would tend to close the openings more rapidly than if uniformly distributed, and would thus materially contribute to the success of the operation?

Mr. Harris.—No, sir; I observed the most striking features. When I saw that edge, there followed instantly the thought, "I have it now."

Mr. Worthen.—How did you find the cement and sand; did they keep together?

Mr. Harris.—They kept together admirably; the accretion was formed of cement and sand both.

Mr. Clarke.—Did you have any trouble from the clogging of your pump?

Mr. Harris.—Yes, sir; I began the work with head alone; subsequently I used the pump. The pump would clog when using coarse sharp sand; I tried different qualities of sand and finally obtained a kind that would carry with the cement.

The Chair.—I have had some experience in grouting. If coarse sand is used, the specific gravity of the cement and sand is so different that they will not mix well together; but when a quality of sand can be procured too fine possibly for ordinary masonry, but which in fineness and general density is somewhat similar to cement proper, the mixture is satisfactory and the grout in place is generally found to be homegeneous.

On motion of Mr. North, a vote of thanks was tendered to Mr. Harris for his original and interesting paper.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

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(Vol. XXIV.—April, 1891.)

COMPARISON OF WATER SUPPLY SYSTEMS FROM A FINANCIAL POINT OF VIEW.

By J. LELAND FITZGERALD, M. Am. Soc. C. E.

WITH DISCUSSION.

The tables given in the following brief paper were not collected by the writer for the purpose of presentation to this Society, but in order to prove on general principles certain assumptions in relation to the comparative efficiency of the three general systems of water supply. The data was gradually extended as each new fact failed in its turn to perform the expected duty, until finally was brought about, if not a change of view, at least an agnostic position in the mind of the writer.

Although there are probably a number of misstatements in the tables, yet a sufficiently large number being verified by comparison with official reports, due allowance being made for differences in dates, it is believed that they are, in the main, correct.

For the data by means of which Table No. 3 and the greater part of Table No. 1 are calculated, credit must be given to the invaluable "Manual of American Water-Works for 1888."

The thanks of the writer are due to the superintendents of the

TABLE No. 1.

Name of Town.	Date of First Construction.	Estimated Population.	Miles of Mains.	Number of Taps.	Total cost divided by 3 650.	Annual operating expenses divided by 365.	Pressure in pounds.	Gallons consumed daily in millions.	Foot pounds in millions.	Foot pounds in millions for each $1 of total cost, divided by 3 650.	Foot pounds in millions for each $1 of daily expense.	Foot pounds in millions for the sum of the preceding.	Foot pounds in millions for total daily expenditures considered on the basis of 10 lbs. pressure.	Minimum meter rates in cents.	Total Cost for 1 000 gallons in cents.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SYSTEM.—PUMPING TO RESERVOIR.															
Cincinnati, O.	1820	275 000	247	31 128	$2 158	$752	100	32 079	26 626	12.3	35.4	9.1	0.91	9	9.1
Baltimore, Md.	1807	400 000	358	66 089	2 994	293	60	34 000	16 932	5.6	57.8	5.1	0.85	8	9.6
Pittsburgh, Pa.	1826	215 000	175	16 000	1 239	545	70	30 000	17 430	14.1	31.9	9.8	1.40	5	5.9
Brooklyn, N. Y.	1856	770 000	397	79 073	3 603	1 603	40	46 278	15 364	4.3	9.5	2.9	0.72	10½	11.2
Philadelphia, Pa.	1800	1 000 000	876	163 816	4 125	1 624	20	88 850	14 749	3 5	9.1	2.5	1.25	8	6.4
Boston, Mass.	1848	400 000	574.3	72 039	5 826	1 362	38	37 481	11 827	2.0	8.7	1.6	0.42	20	19.2
St. Louis, Mo.	1830	450 000	315	34 022	3 575	743	40	31 500	10 458	2.9	14.0	2.4	0.60	12½	13.6
San Francisco, Cal.	1856	250 000	250	26 000	4 675	2 200	60	19 112	9 536	2.0	4.3	1.4	0.23	.....	36.0
Detroit, Mich.	1836	200 000	323	32 938	1 125	294	25	36 079	7 487	6.6	25.4	5.2	2.08	10	3.9
Cleveland, O.	1854	230 000	252	22 658	1 490	247	40	22 266	7 392	5.0	30.0	4.4	1.10	6¾	7.8
Milwaukee, Wis.	1872	185 000	148	14 072	829	329	38	20 089	6 336	7.6	19.2	5 4	1.42	4½	5.7
Allegheny, Pa.	1847	80 000	27	3 300	450	248	40	17 824	5 918	13.1	23.8	8.5	2.12	15	3.9
Omaha, Neb.	1880	100 000	75	3 500	825	124	100	7 500	6 225	7.5	50.2	6.5	0.65	.....	12.6
Jersey City, N. J.	1852	155 000	160	16 936	1 362	1 482	40	16 500	5 478	4.0	3.7	1.9	0.47	16⅔	17.2
Richmond, Va.	1830	85 000	73.4	8 900	413	84	41	11 133	3 788	9.1	45.1	7.6	1.85	.....	4.4
Harrisburg, Pa.	1844	40 000	30	6 000+	192	68	60	6 400	3 187	16.6	46.8	12.2	2.03	.....	4.0
Louisville, Ky.	1857	165 000	137.4	11 001	1 378	163	35	10 307	2 994	2.2	18.3	1.9	0.54	6	15.0
Portland, Ore.	1858	40 000	18	.....	138	130	60	5 000	2 490	18.0	19.1	9.3	1.55	.....	5.3
Nashville, Tenn.	1832	80 000	42	4 321	550	119	35	8 523	2 476	4.5	20.8	3.6	1.02	.....	7.8
Newark, N. J.	1800	160 000	161	12 207	734	284	23	12 642	2 413	3 3	8 5	2.3	1.00	5	8.1
Lowell, Mass.	1872	70 000	83	7 440	1 174	92	60	4 319	2 151	1.8	23.3	1.6	0.27	15	29.4
Leavenworth, Kan.	1882	31 000	23	1 128	103	41	125	1 800	1 867	18.1	45.5	12.9	1.03	.....	8.0
Cohoes, N. Y.	1848	21 000	25	1 200	73	33	70	3 000	1 743	23.8	52.8	16.4	2.34	.....	3.5
Wheeling, W. Va.	1831	35 000	41	6 900	206	76	45	4 500	1 681	8.1	22.1	5.9	1.31	.....	6.2

Erie, Pa	1867	35 000	56.5	6 367	$268	$48	60	3 335	1 661	6.2	34.6	5.2	.87	6	9.6
Providence, R. I	1870	125 000	202	13 128	1 714	192	39	4 925	1 554	0.9	8.1	0.8	.20	15	38.9
Toledo, O	1873	80 000	56	2 875	344	63	50	3 700	1 536	4 4	24.3	3.7	.74	8	11.0
Wilmington, Del	1804	42 000	69.5	10 869	209	138	35	5 272	1 532	7.3	11.1	4.4	1.25	10	6.5
Grand Rapids, Mich	1873	60 000	28	1 750	146	62	65	2 769	1 498	10.2	24.1	7.2	1.10	.....	7.3
Sacramento, Cal	1854	35 000	35	4 600	96	69	30	6 000	1 494	15.5	21.6	9.0	3.00	.....	2.7
Lawrence, Mass	1873	40 000	53.6	4 447	537	64	70	2 500	1 453	2.7	22.7	2.4	.34	20	24.0
Hoboken, N. J	1855	75 000	78.5	5 559	268	149	40	4 250	1 411	5.2	9.3	3.4	.85	.....	9.7
Oswego, N. Y	1868	24 000	38	1 000	138	45	50	3 000	1 245	9.0	27.6	6.7	1.34	.....	6.1
New Orleans, La	1833	230 000	72	4 400	659	109	25	6 000	1 245	1.9	11.4	1.6	.64	.....	12.8
Lynn, Mass	1870	51 400	81	7 800	377	61	62	2 379	1 225	3.2	20.0	2.8	.45	20	18.2
Little Rock, Ark	1878	35 000	12	1 044	118	65	70	2 000	1 162	9.9	46 4	8.1	1.15	.....	9.1
Council Bluffs, Ia	1882	35 000	25	1 400	172	28	82	1 700	1 157	6.7	41.3	5.8	.71	.....	11.7
San Antonio, Tex	1878	45 000	70	4 000	187	55	65	2 000	1 079	5.7	19.6	4.4	.67	.....	12.1
Fall River, Mass	1871	65 000	60	4 197	482	69	80	1 591	1 056	2.2	15 3	1.9	.24	29	34.4
Springfield, O	1881	35 000	32.5	1 699	120	36	80	1 500	996	8.3	27.6	6.3	.78	20	10.4
Lancaster, Pa	1836	32 000	32	5 200	165	32	28	4 000	930	5.6	29.1	4.7	1.68	.....	4.9
Sandusky, O	1875	23 000	25	1 618	113	35	60	1 759	876	7.7	25.0	5.9	.98	20	8.2
Manchester, N. H	1872	41 000	49.5	3 100	248	41	62	1 750	901	3.6	22.0	3.1	.50	26⅔	16.0
Camden, N. J	1860	55 000	52.7	908	192	55	20	5 267	874	4.5	15.9	3.5	1.75	.....	4.6
Salem, Mass	1865	28 000	50	5 016	392	70	40	2 580	856	2.2	12.2	1.8	.45	.....	17.7
New Bedford, Mass	1865	36 000	54.4	5 495	357	72	33	3 047	835	2.3	11.5	1.9	.57	.....	14.3
Elizabeth, N. J	1854	35 000	45	3 000	275	110	30	2 500	623	2.2	5.6	1.6	.53	.....	15.4
Lynchburg, Va	1828	25 000	16	1 300	47	22	60	1 250	622	13.2	28.3	9.0	1.50	.....	5.3
New Port, Ky	1872	27 500	26.6	3 256	209	27	80	900	598	2.8	22.1	2.5	.31	15	26.2
Poughkeepsie, N. Y	1870	22 000	18.4	1 790	161	50	40	1 767	587	3.6	11.7	2.8	.70	.....	11.7
Trenton, N. J	1855	40 000	40	8 102	123	41	30	2 256	562	4.5	13.7	3.4	1.13	.....	7.1
Springfield, Ill	1866	30 000	32	1 700	151	61	20	2 441	405	2.6	6.6	1.9	.95	.....	8.8
Quincy, Ill	1873	36 000	20	1 150	12	41	35	671	195	16.2	4.7	3.6	1.02	15	7.9
Petersburg, Va	1856	25 000	11	1 080	42	25	24	750	149	3.5	6.0	2.2	0.91	.....	9.0
								Average	.....	6.85	22.30	4.85	1.01	.....	11.77
SYSTEM.—DIRECT PUMPING.															
Chicago, Ill	1852	775 000	638.2	100 000	$3 132	$2 794	25	91 648	19 017	6.0	6.8	3.2	1.28	8	6.4
Buffalo, N. Y	1852	250 000	250	29 467	1 238	349	30	38 485	9 583	7.7	27.4	6.0	2.00	3	4.2
Kansas City, Mo	1873	110 000	85	7 786	1 238	154	90	10 000	7 470	6.0	48.5	5.4	.60	15	13.9
Minneapolis, Minn	1867	160 000	112	5 598	391	187	80	10 814	7 181	18.3	38.4	12.4	1.55	10	5.2
Columbus, O	1870	95 000	70.2	5 207	319	84	70	5 816	3 379	10.5	40.2	8.3	1.18	7	6.9
Savannah, Ga	1853	52 000	32.6	2 850	83	36	30	5 715	1 423	17.1	39.5	11 9	3.96	.....	2.1
Des Moines, Ia	1871	45 000	40	2 500	275	55	80	2 000	1 328	4.8	24.1	4.0	0.50	.....	16.5
Evansville, Ind	1870	60 000	33.5	2 230	138	109	40	4 000	1 328	9.6	12.2	5.3	1.32	.....	6.2
Schenectady, N. Y	1871	25 000	17	1 300	41	21	85	1 500	1 058	25.8	50.4	17.0	2.00	8	6.2
Davenport, Ia	1874	31 000	28	1 523	237	69	60	2 000	996	4.2	14.4	3.2	.53	.....	15.3
Peoria, Ill	1867	45 000	47	3 000	124	88	40	3 000	996	8.0	11.3	4.6	1.15	.....	7.1
East Saginaw, Mich	1873	32 500	40	1 911	134	44	40	2 813	934	7.0	21.2	5.2	1.30	.....	6.3

TABLE No. 1.—*Continued.*

Name of Town.	Date of first Construction.	Estimated Population.	Miles of Main.	Number of Taps.	Total cost divided by 3 650.	Annual operating expenses divided by 365.	Pressure in pounds.	Gallons consumed daily in millions.	Foot pounds in millions.	Foot pounds in millions for each $1 of total cost, divided by 3 650.	Foot pounds in millions for each $1 of daily expense.	Foot pounds in millions for the sum of the preceding.	Foot pounds in millions for total daily expenditures considered on the basis of 10 lbs. pressure.	Minimum meter rates in cents.	Total cost for 1 000 gallons in cents.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SYSTEM.—DIRECT PUMPING.—*Continued.*															
Augusta, Ga	1859	46 000	30	1 728	$55	$15	35	2 755	800	14.5	53.3	11.4	3.25	.....	2.7
Dayton, O	1869	55 000	37	1 799	270	52	50	1 851	768	2.8	14.7	2.4	.48	10	17.9
Bay City, Mich	1872	33 000	25.5	1 332	118	32	40	2 266	752	6.3	23.5	5.0	1.25	.....	6.5
Burlington, Ia	1877	30 000	19.5	1 477	55	41	90	1 000	747	13.5	18.2	7.7	.85	.....	9.6
Topeka, Kans	1881	40 000	28	1 450	55	39	110	800	730	13.2	18.7	7.8	.71	.....	11.7
Norfolk, Va	.....	30 000	30	3 925	218	41	30	2 378	592	2.7	14.4	2.2	.73	.....	10.8
Atlanta, Ga	1874	66 000	27	2 000	124	49	40	1 575	523	4.2	10.6	3.0	.75	.....	10.8
Ft. Wayne, Ind	1880	35 000	30	1 669	86	25	40	1 400	465	5.4	18.6	4.2	1.05	.....	8.0
Terra Haute, Ind	1873	40 000	28	800	95	22	35	1 250	363	3.8	16.5	3.1	.88	.....	9.0
Covington, Ky	1868	38 000	28	2 500	110	69	30	1 500	374	3.4	5.4	2.1	.70	15	12.0
Taunton, Mass	1876	25 000	54.6	2 892	151	44	40	725	241	1.6	5.5	1.2	.30	.....	26.7
								Average	.....	8.54	23.21	5.94	1.23	.....	9.6
SYSTEM.—GRAVITY.															
New York, N. Y	1835	1 700 000	620	180 000	$10 970	$1 644	10	110 000	9 130	0.83	5.56	0.73	.73	13½	11.5
Washington, D. C	1853	160 000	128	22 095	2 338	38	20	26 148	4 340	1.9	114.2	1.83	.91	10	9.1
Troy, N. Y	1880	60 000	53.2	5 250	322	140	60	8 000	3 984	12.4	28.4	8.6	1.43	10	5.8
Worcester, Mass	1852	79 500	110	8 110	482	259	100	4 000	3 320	6.8	12.8	4.4	.44	15	18.5
Springfield, Mass	1873	40 000	81.5	4 819	367	69	90	4 000	2 988	8.1	43.3	6.8	.75	10	10.9
Hartford, Conn	1854	48 000	80	5 836	467	78	60	5 000	2 490	5.3	32.0	4.5	.75	10	10.9
Portland, Me	1867	34 000	96	6 425	413	40	60	5 000	2 490	6.0	62.2	5.5	.92	.....	9.1
Rochester, N. Y	1872	130 000	216	17 000	1 063	83	40	7 200	2 390	2.2	28.8	2.1	.52	5	16.0
Oakland, Cal	1866	45 000	164	7 400	1 430	330	40	7 000	2 324	1.6	7.0	1.3	.32	.....	25.1
Reading, Pa	1865	60 000	58.9	21 940	320	40	50	4 000	1 660	5.2	41.5	4.6	.92	10¾	9.0
Holyoke, Mass	1873	31 500	42.4	2 713	132	22	72	2 246	1 341	10.1	60.9	8.6	1.19	.....	6.8
Elmira, N. Y	1860	27 000	40	1 500	143	36	44	2 250	822	5.7	22.8	4.6	1.04	10	7.9
Altoona, Pa	1871	30 000	35.8	5 272	98	44	50	175	73	0.74	1.6	0.51	.10	.....	81.1
								Average	.....	5.14	35.46	4.16	.77	.....	17.0

various water-works whose annual reports furnished the data on which Table No. 2 is based.

Table No. 1 contains water-works data of all towns in the United States having in 1880 a population of over 15 000, and whose reports were sufficiently full for purposes of comparison. The omissions are chiefly among those supplied by private companies. Column 1 contains the names of the towns; column 2, the date of original construction, when the present works are a direct outgrowth of the first, or of the date of complete reconstruction; column 3, the estimated present population, probably in all cases somewhat in excess of the true; column 4, the number of miles of pipes; and column 5, the number of taps. In column 6, 10 per cent. of the total cost is taken as a basis of comparison. Although this may seem excessive, yet when it is remembered that nearly every water-works in the country is practically reconstructed every twenty or thirty years, that the rate of interest paid is from 3 to 7 per cent., and that the life of pipe systems, pumps and boilers, is certainly less than twenty years, it will be seen that the proportion taken is, if anything, too small. Even a gravity system with masonry conduits, intended to last indefinitely, will begin to grow so inadequate, as to involve changes of such a general character, that a much less enduring original construction might well have been adopted had the sequel been known in advance.

Column 7 gives the daily operating expense ; column 8, the pressure in pounds; and column 9, the daily consumption in millions of gallons. Column 10 gives the work done in furnishing the supply in millions of foot-pounds. There is evidently no question, when comparing the efficiency of systems, as to the fairness of making the pressure a factor. The lack of it often makes the difference between a small fire and a great conflagration, while an excessively low head for daily service causes (as in New York) an individual expense whose aggregate, although unknown, must be enormous.

Column 11 gives the work done in millions of foot-pounds for each dollar of the 10 per cent. interest and sinking fund; column 12, the same for operating expenses alone; column 13, for each dollar of the total daily expenditure, including both interest and maintenance; column 14 is the same as 13, but with the pressure factor eliminated; column 16 gives the total cost per thousand gallons in cents; it is, therefore, the same as 14, but with the results presented in a different

manner to correspond with common usage. Column 15 gives the minimum meter rates so far as they could be obtained.

It is curious to observe that, if the basis of the table is correct, and the general rates are based on the meter rates, nearly all the water-works in the country sell below the cost of production. Meter rates seem, in fact, when on any basis, to take into account simply the operating expense and annual interest. This is very apparent in Table No. 2.

It is difficult to select any single factor on which the efficiency, or what is the same thing, the proportionate cost, of any one plant depends. The writer plotted the data in nearly every combination, but while there was a tendency toward a law, it was by no means a simple one. Plotted with respect to date of construction, gravity and reservoir systems show a decided tendency to vary inversely with the age of the works, while direct pumping gives a horizontal line. When five-year averages of the two former are taken, not only is the age factor more apparent, but the curves of the two systems are almost exactly parallel between 1855 and 1888. This is the more noticeable from the great irregularities exhibited in certain years, and can therefore be attributed entirely to current market prices.

When plotted with respect to number of miles of mains, direct pumping shows no relation whatever; gravity a slight inverse ratio, that might be accidental; and reservoir systems an inverse ratio in the small systems, but none in the large. It is to be inferred therefore that the size of the town, as indicated by the number of miles of mains, either has no effect on the efficiency, or that its effect is concealed under more important factors.

Plotted with reference to first cost, the total efficiency of gravity and reservoir systems has an inverse ratio, but direct pumping shows no relation.

With reference to daily consumption, the total efficiency of gravity and reservoir systems has a decided inverse, while direct pumping has an equally decided direct ratio to the amount of water used.

Comparing the averages of all, with respect to efficiency based on first cost alone:

Gravity gives	5.14
Pumping to reservoir	6.85
Direct pumping	8.54

If one town (Altoona) be omitted from the list of gravity systems, the efficiency of the latter will be about the same as the reservoir systems.

Based on operating expense alone:

Gravity gives	35.46
Pumping to reservoir	22.30
Direct pumping	23.21

It will be seen, by comparison with Table No. 2, that the difference in favor of the gravity systems represents pump-house expenses, the latter being about half the total for maintenance.

Based on the combined expense of interest, sinking fund, and maintenance:

Gravity gives	4 16
Pumping to reservoir	4.85
Direct pumping	5.94

Correcting the gravity average for the one town will make it nearly the same as the reservoir systems, leaving a balance in favor of direct pumping of about 20 per cent.

Taken on the same basis as the preceding, but with the pressure reduced to 10 pounds:

Gravity gives	0.77
Pumping to reservoir	1.01
Direct pumping	1.23

The percentage in favor of direct pumping being the same as the preceding.

The total average cost per thousand gallons in cents will be:

Gravity	17.1
Pumping to reservoir	11.77
Direct pumping	9.6

Again omitting Altoona from the gravity systems, the latter will give an average of twelve cents per thousand gallons. Direct pumping as before has 20 per cent. advantage.

From this table we are, therefore, justified in concluding that the efficiency for large towns is the same for gravity and reservoir systems, and that direct pumping has about 20 per cent. advantage; that for the former two it will vary inversely with the age of the works, the size of the town, the quantity of water consumed, and the original cost. Also, that the efficiency of direct pumping in the works reported is independent both of the age and original cost, and increases directly with the consumption. These ratios do not, of course, apply to small towns where the addition of a reservoir of twenty hours capacity adds but 12 per cent. to the total cost and diminishes the pumping expenses by nearly one-half.

Table No. 2 is deduced from current official reports of the towns in question, and is self-explanatory. Pressures are given in feet, the dynamic head being used when procurable. The interest is that actually paid by the town, and includes no sinking fund account. The prices are unduly high, compared with Table No. 1, being compiled chiefly from New England reports. Taking them as they are, the percentage to be added to the total cost, in order to make the price per thousand gallons cover the sinking fund used in Table No. 1, is for gravity, 70; for reservoir, 30; and for direct pumping, 110 per cent.

It will be noticed that the cost per thousand gallons due to the interest account is for gravity, 67; for reservoir, 63; and for direct pumping, 51 per cent. of the total. The total operating expense is nearly the same for gravity and direct pumping, the difference in favor of the latter being due to a smaller first cost. The operating expense for gravity and reservoir systems is the same, if from the latter be deducted the pump-house account.

The number of examples taken is too small to show the ratios of Table No. 1.

Table No. 3 is added to show what has been the practice of designers of water-works in this country. In the percentage column it will be seen that the proportion of gravity systems grows smaller with the date. This is due to several reasons, among the most important of which are: All cheaply available supplies will be secured as soon as the need is felt, so that a great number will date almost from the beginning of the history of the town; favored localities are comparatively few in number; and, finally, the total proportion is greatly dwarfed owing to the number of smaller works built during recent years. On the other hand, the ratio is increased beyond its merits, owing to a popular prejudice that compels a designer, whatever his private judgment may be, to seek a gravity supply whose possible cost will be based less on its relative value than on the paying ability of the town.

Reservoir systems keep nearly the same ratio throughout.

Direct pumping came into favor about 1870. It was at first regarded more as a makeshift, compelled by the combination of general financial depression and high prices of material, than as a permanent system, but as pumps more adapted to that special service appeared, the method soon grew into favor as a recognized system of supply. Being under great disadvantage when the consumption is small, the reservoir-stand-

TABLE No. 2.—DISTRIBUTION OF COST.

Name of Town.	Kind of System.	Head in feet.	Quantity in Million Gallons.	Date of Report.	Cost of Water per 1 000 Gallons in Cents, Due to: Interest on Bonds.	Engineering Administration or Superintendence.	General Repairs and Maintenance.	Total Pumping Expense, including Salaries and Repairs.	Total cost per 1 000 Gallons in Cents.	Meter Rate in Cents.
Springfield, Mass.	Gravity.	210[1]	1 460	1889	5.61	1.27	.... 0.92	....	7.80	15.7[3]
Fitchburg, Mass.	"	186[1]	480	1889	5.82	....	1.41	....	7.23	11.6[3]
Gloversville, N. Y.	"	250[1]	183[1]	1880	2.67	....	0.32	....	2.99	....
St. John's, N. B.	"	92	1 692	1888	3.39	....	0.49	....	3.88	....
Northamptom, Mass	"	200[1]	55[1]	1889	15.45	3.66	.... 1.54	....	20.35	6.0[4]
Worcester, Mass.	"	170[1]	1 735	1889	1.98	....	3.17	....	5.15	17.6[3]
Hartford, Conn.	"	140	500[1]	1890	9.68	2.14	.... 4.06	....	15.88	10.0[7]
Little Falls, N. Y.	"	325	1 460[8]	1889	0.65	....	1.07	....	1.72	3.0
Johnstown, N. Y.	"	230	183[1]	1889	2.00	0.44	.... 0.81	....	3.25	15.0[4]
Bradford, Pa	"	219	409[1]	1889	0.88	0.39	.... 1.68	....	2.95	....
				Average	4.813	....	2.337	....	7.12	11.3
Fall River, Mass	Pumping to Reservoir.	185	685	1890	14.10	0.92	.... 1.58	1.25	17.85	29.1[3]
Cambridge, Mass.		65[1]	1 526	1889	5.56	0.28	.... 1.74	0.75	8.33	15.0[3]
Plymouth, Mass.[5]		84[1]	95	1889	4.42	1.70	.... 3.69	1.26	11.07	....
New Bedford, Mass.	"	128	1 298	1889	3.75	0.51	.... 0.60	0.80	5.66	....
Natick, Mass.	"	140[1]	93	1890	4.90	2.23	.... 0.30	1.93	9.36	....
Manchester, N. H.	"	144[1]	676	1889	5.32	....	1.86	0.67	7.85	26⅔[7]
Troy, N. Y.	"	242	2 856	1890	0.56	....	0.70	1.21	2.47	5.0[4]
Hudson, N. Y.	"	..	553	1889	1.08[1]	0.36	.... 0.37	1.12	2.93	None.
Bridgeton, N. J.	"	60[1]	102	1889	4.35	1.04	.... 0.60	1.17	7.16	....
Nashville, Tenn.	"	308[1]	3 796	1889	1.06[1]	....	0.58	0.68	2.32	10.0
Newport, Ky.	"	260	475	1889	12.83	0.78	.... 1.26	2.72	17.59	15.0[7]
Malden, Mass.	"	130	365[1]	1889	7.50	1.09	.... 3.75	1.10	13.44	....
Lawrence, Mass	"	161[1]	961	1889	8.11[9]	....	0.95	0.91	9.97	14.7[3]
Waltham, Mass.	"	192	208	1889	9.46	....	4.05	1.95	15 46	26. [7]
				Average	5.93	....	2.21	1.25	9.39	17.7
Taunton, Mass.	Direct Pumping	152	281	1889	9.4	1.20	.... 1.99	1.21	13.80	16.9[3]
Schenectady, N. Y.		165	876	1889	0 47	....	0.63	1.60	2.70	....
Detroit, Mich.	"	49	12 875	1889	0.58	0.21	.... 0.12	0.48	1.39	10. [7]
Columbus, O.	"	187	2 259	1889	1.64	0.44	.... 0.26	0.70	3.04	6.0[4]
Atlanta, Ga.	"	322	757	1889	4.06[1]	....	1.34	2.33	7.73	17.0[6]
East Saginaw, Mich.	"	93[1]	1 151	1889	1.88	....	0.48	0.92	3.28	11.2[3]
Kalamazoo, Mich.	"	100	628	1888	0.0[2]	....	0.25	1.39	1.64	....
Mansfield, O.	"	230	457	1889	0.31	0.32	.... 0.99	0.97	2.59	....
				Average	2.29	....	1.03	1.20	4.52	12.2

1. Taken from other than official reports.
2. No debt.
3. Average of all water used through meters.
4. Minimum rate.
5. Part of supply by gravity (not given).
6. To all classes except manufacturers.
7. Doubtful.
8. Excess over consumption runs to waste.
9. Interest on first cost

TABLE No. 3.

Number of Works Built in the United States and Percentage of Kind in Each Year.

Date.	Number of Each Kind Built.					Total Number.	Percentage of Each.					
	Gravity.	Direct Pumping.	Pumping to Reservoir.	Pumping to Stand-Pipe.	Pumping to Tank.		Gravity.	Direct Pumping.	Pumping to Reservoir.	Pumping to Stand-Pipe.	Pumping to Tank.	Pumping to Reservoir, Stand-Pipe and Tank.
Before 1840	15	1	7	0	2	25	.60	.04	.28	0	.08	.36
From 1840–49	4	0	10	0	0	14	.28½	.00	.71½	0	0	.71½
" 1850–59	22	3	15	1	1	42	.52	.07	.36	.02½	.02½	.41
" 1860–64	17	1	2	1	0	21	.81	.05	.09	.05	0	.14
" 1865–69	36	10	18	1	2	67	.53	.15	.27	.01½	.03½	.32
" 1870–74	69	42	43	8	10	172	.41	.24	.25	.04½	.05½	.35
" 1875–79	63	33	54	17	26	193	.33	.17	.28	.09	.13	.50
During 1880	17	8	7	3	0	35	.48½	.23	.20	.08½	0	.28½
" 1881	16	7	11	4	5	43	.37	.16	.25	.10	.12	.47
" 1882	24	23	13	15	11	86	.28	.27	.15	.17	.13	.45
" 1883	27	14	13	14	16	84	.32	.17	.15	.17	.19	.51
" 1884	25	19	30	19	19	112	.22	.17	.27	.17	.17	.61
" 1885	25	21	22	15	18	101	.25	.21	.21	.15	.18	.54
" 1886	24	20	38	36	21	139	.17	.14	.27	.26	.16	.69
" 1887	35	22	27	60	25	169	.21	.13	.16	.36	.14	.66
" 1888	38	26	40	81	53	238	.16	.11	.17	.34	.22	.73

pipe system becomes its natural development under such conditions, and we therefore find the percentage of the latter showing an inverse ratio with the direct system. That the stand-pipe modification is a favorite in small towns is seen by its frequent use in the later works, the greater part of the latter being of moderate size.

Disregarding the gravity systems, as being entirely dependent upon local conditions, the arguments in favor of the reservoir, as opposed to direct pumping, are usually based on the following suppositions:

First.—Better fire protection due to the storage of a large quantity of water.

Second.—Greater economy in running expenses with longer life to pump and boiler.

Third.—Purer water due to sedimentation in the reservoir.

With respect to superior fire protection the somewhat meager statistics in possession of the writer prove little, and that little is in favor of the direct system. Large towns that depend upon their pumps have always a duplicate plant that can be brought into service at a moment's notice, with a hydrant pressure that is usually limited only by the strength of the pipe system. The pump in daily use can be, and often is, run at its full and most economical capacity, giving a "life duty" that well compensates for its idle brother. Since the boilers supplying steam to the daily service pump are, as a rule, taxed only about 50 per cent. of their full capacity, the reserve pump can be brought into service at once. It can also be noted that the mere knowledge of the fact that the town is dependent upon the perfect working of the pump, and that even a stoppage of a few minutes will be commented upon and probably investigated, tends to a greater watchfulness and care on the part of the men in charge, with a saving of the proverbial nine stitches. The importance of the service also demands, and usually obtains, a better paid and more skillful class of labor.

As the consumption increases in amount the extra pump, being usually of greater capacity than that used in daily service, takes the place of the latter, and a new one is purchased to perform guardian duty. The old one then, if not worn out, can be sold for some fair percentage of its original cost, as it is still useful in many situations where a high duty is not required. It is thus seen that the purchase of a duplicate plant antedates but a few years the actual necessity, and is losing nothing but the interest of the investment.

When in a reservoir system the method is adopted of pumping but half the time, the outlay for engines will be at least equal to the duplicate plant of the direct system. The strains in the boilers induced by partial cooling each night, when the fires are banked, must have also an injurious effect upon their durability.

With regard to the purifying action of storage reservoirs the writer is of the opinion that, with the exception of the removal of the grosser particles, water is far more injured than improved by the process. The mud and slime that is deposited in the bottom undergoes decomposition whenever the weather permits, sustaining an infinite number of evil smelling plants. There is also usually a fouling of the whole body of water at each decided change of temperature.

The removal of the first cause, the mud, could more easily, and certainly more perfectly, be attained by some one of the many good forms of mechanical filters. A battery of these can be purchased for about one-quarter of the first cost of a reservoir, while they have the great advantage of permitting, with small waste of water, so frequent cleaning as to prevent the first beginning of decomposition.

If then, from the above data any conclusions can be drawn, they may be summarized as follows, supposing in every case that the three systems of supply are open to choice: Whatever the size of the town, a gravity system would be most efficient whenever these conditions are fulfilled—the supply of unquestioned present and future purity; the quantity sufficient for the needs of the next twenty years without great additional outlay; and the original cost such that 8 per cent. thereof will not be greater than 60 per cent. of the total operating expense, including interest and sinking fund.

A direct pumping system will be the most economical; when the town is of such a size that its daily consumption will be more than one-half million gallons; when the supply is good and abundant, but situated at a low level; and when there are no great differences of elevation in the distribution system. If there are highly elevated portions, these, when of small comparative area or consumption are best supplied with a reservoir system, having an independent force main. When the consumption is less than one-half million gallons, direct pumping with a reservoir-stand-pipe of at least twenty hours capacity, situated in the distribution system, will give the most economical results.

When a town is so unfortunate that its supply is insufficient during certain portions of the year, or when that supply is sufficient for ordinary needs, but affords no margin for fire protection, a reservoir of large capacity will then be necessary. Works of the latter kind can only be regarded as temporary in character, the inevitable growth of the city forcing soon radical changes and possibly reconstruction.

Although the writer is aware that no hard and fast rules can be formulated for a choice of a system, and that a hundred local circumstances will determine the final selection, yet he believes that a few general principles like the above will afford some aid to the solution of doubtful cases.

Before leaving the subject it may be well to call attention to the lack of accurate data as to the life of various parts of a water-works system. Although such data undoubtedly exist in the offices of each plant, they are only available to the profession through the brief and detached hints found in annual reports. Who can tell, except in individual cases, what is the average life of a pump, and how much has been spent on it for repairs, or under what condition of soil a cast-iron pipe will last five years or thirty?

The financial data furnished in annual reports are also capable of improvement. Not more than one-quarter of those in the possession of the writer were available in preparing Table No. 2, as many that gave full particulars of operating expenses neglected to state the consumption; no distinction was often made between renewals and extensions, and in a great number of cases no interest account was given. It is manifestly unfair, also, when comparing the efficiency of different towns, to charge a percentage sinking fund against an original cost, the major portion of which has long been paid.

DISCUSSION.

Desmond FitzGerald, M. Am. Soc. C. E.—I have been asked to open this discussion. It is a task I do not particularly enjoy, and should much prefer to have some one else begin, as I do not find myself at all in sympathy with this paper, and my remarks must necessarily be in the nature of criticism. I am very sorry that the author of the paper is not present, for it always seems to me that one can speak more unreservedly if the author is present to defend his osition; however, there

are certain duties that we owe to our profession. I must confess to disappointment in the data and results contained in Mr. FitzGerald's paper.

In Table No. 1 the Boston works, for instance, are classified under the head of "Pumping to Reservoir."

In round numbers, of the 40 000 000 of gallons supplied to Boston daily, there are about 14 000 000, including the Mystic works, so called, which are pumped. Our main supply is carried to the city by the Cochituate and Sudbury River aqueducts by gravitation, and then about 6 000 000 of gallons daily are pumped, within the city limits, to a high service reservoir with a separate distribution system, so that I have always been accustomed to look upon the Boston supply as principally a gravity system. Sixty-five per cent. of the consumption is gravity, pure and simple, and of the remaining 35 per cent. nearly one-half is brought from the sources by gravity before passing through the pumps. These facts are all set forth fully in our annual reports. Aside from errors such as this, I think there are some points made in the text of the paper, against which we should raise a mild protest. Is it possible, from facts like those contained in Table No. 1, to produce a set of hard and fast rules applicable to all or even a majority, of cases? It seems to me that we must consider each case of water supply under its own particular conditions, and that serious errors are liable to arise from lumped classification, taken from statistical tables. I should at least advise any who are just setting out in the water supply branch of the profession, to study very carefully the data contained in this paper before accepting the conclusions.

I notice on page 5 the life of pipe systems is set down as "certainly less than twenty years." I should think this a very short period to take as the life of a cast-iron pipe.

As to the effects of storage upon a water supply system, it strikes me that the writer has fallen into serious error. It will be found, I think, that the only waters which deteriorate on storage in properly prepared reservoirs, are those which are filtered or taken from subterranean sources. As is already well understood, these waters should be stored only in closed reservoirs. The storage in our Boston works amounts to about 6 000 000 000 of gallons, and in the management of this storage, I have had an opportunity to watch for a number of years the effects of storage. The results to which I have arrived are, that surface waters are never injured by proper storage; on the contrary, that the chances are in the great majority of cases that they will be very materially improved, and further, that the poorer the quality of the water, or its equivalent, the greater the amount of organic matter in process of change, the greater will be the benefits of storage.

I have abundant facts and figures to fortify this position, but this is hardly the proper opportunity to enter into an extended argument. I should like to state, however, that I have found most certainly,

that the different forms of nitrogen which represent the first steps in putrefaction, such as free and albuminoid ammonia and the nitrites, are lessened in proportion to the length of the time of storage; the color is lessened, and the impurities, so called, rendered more inocuous.

From long experience and many experiments on a large scale, I have found that the effects of storage are very different when a reservoir is properly prepared by removing the shallow flowage, and taking out the loam, muck, stumps and other objectionable matter from the bottom and sides of a valley, before flowing it with water for a domestic supply. If no pains are taken in the preparation of the basin or reservoir, if we store water over a swamp or other source of decaying vegetable matter, we must expect to pay the penalty. But I am afraid I am making my discussion too long and will close with the remark that there is one clause in the paper with which I can agree most heartily, and that is that "no hard and fast rules can be formulated for the choice of a system, and that a hundred local circumstances will determine the final selection."

James B. Francis, Past President Am. Soc. C. E.—I should like to know under what condition of soil the cast-iron pipe will last only five years. It is within my experience and knowledge that pipes at Lowell, which were obtained from Philadelphia in 1830, were then intended to be used under a pressure of 150 feet head, and are now in use under 200 feet head, without any signs of failure after sixty years' use.

F. L. Fuller, M. Am. Soc. C. E.—I question the statement that the life of pipe systems is not more than twenty years. I think there are a great many pipe systems that have stood longer than that; and also the statement that many water companies sell water below the cost of production.

Charles B. Brush, Director Am. Soc. C. E.—I agree very heartily with the remarks made by Mr. Desmond FitzGerald in relation to this paper, and I agree with one paragraph of the paper, viz.: "It may be well to call attention to the lack of data as to the life of systems, although such data undoubtedly exist." The records in this particular are certainly very brief and unsatisfactory, as they are usually in relation to other important details affecting the operation of waterworks; and it is from just such unsatisfactory records that these data have been collected. Mr. FitzGerald has referred to the different conditions under which a supply is obtained at different points. On one of the works under my control the force main is 17 miles long, on another it is 22 miles long, on another it is only 3 miles long. On one of these works it is necessary to pump the water three times before it reaches the consumer; on the other works it is pumped direct to the consumer. There is no relation whatever between systems which have only a low service and those which have a low and high service. The data upon which this paper has been prepared, I think are utterly inadequate as

a basis for any safe conclusions. The conclusion as drawn seems to me rather peculiar. It is true that in some instances a direct pumping system is perhaps desirable, yet it is strange how many towns, after they have established a direct pumping system, have found it necessary to change, and those changes are being made all over the country. The inference naturally drawn from the paper before us would seem to be, that a direct pumping system was much the most economical. That has not been my experience, and I think before any such general principle is laid down, very much more careful and full investigation should be made. I object to any such conclusion going forth from this Society.

The extreme draft on different systems varies as compared with the average draft, but it is safe to say that the draft in the middle of the day, from 9 to 3 o'clock, is often three times the average draft of any given plant. If you have a direct system you must have at least a pumping capacity equal to the extreme draft; and the pumping capacity will have to be at least three times as great as the pumping capacity on the reservoir system. That carries with it not only the pumps but also the boilers and appurtenances. The strain on a plant which is supplied by direct pressure is always a very serious matter. I have compared the hourly draft of different systems, and I have found the loss greater on a direct system than on a reservoir system.

My own experience is directly the reverse of the conclusions of the writer, and I certainly would not be willing to accept his conclusions unless the data were very much more satisfactory than the data submitted in this paper.

J. B. Johnson, M. Am. Soc. C. E.—I would like to enter my protest against any kind of an argument based on averages where the average is of this kind; this average is the straight arithmetic mean of all the quantities in the table, giving equal weight to all. Thus, for instance, under Pumping to Reservoir, Table No. 1, I take City of Pittsburgh that supplies 30 000 000 gallons a day at a cost of 5.9 cents per 1 000 gallons; he gives that no more weight in his average than the City of Newport, Ky., which pumps 900 000 gallons a day at a cost of 31 cents per 1 000 gallons. In the first place the conditions and the items are so various that an average means nothing; an average would mean nothing even though the cities were all of the same size, but when one city uses fifty times as much water as another and has fifty times larger works, he has given them both exactly the same weight, simply taking an average, counting each city as one. An average like that is worse than nothing, it is misleading. Engineers should know better, for they know that one fact is more significant than another. As he acknowledges that his conclusions are drawn from these tables and not from what his judgment might lead him to conclude from the facts, I submit if this is not absolutely a false basis on which to base an argument for engineers to

use, in settling so important a problem as deciding what kind of a system to use for the water-works of a city.

T. H. McCann, M. Am. Soc. C. E.—Mr. FitzGerald says that there are probably misstatements in his tables; I find this to be the case as regards the City of Hoboken, N. J.

The true statements as to this city are as follows: From 1855 to 1883 Hoboken was a portion of the distribution system of Jersey City. Since 1883 water has been supplied by a private company (The Hackensack Water Company), the supply being paid for by house rates, which are collected by the city authorities and paid to the company, less a percentage to pay for expenses of care of mains, cost of collecting, etc.

The present population is about 43 000 instead of 75 000, and the present length of mains is 20 miles instead of 78.50 miles as given in the tables.

Joseph Ramsey, Jr., M. Am. S. C. E.—I come from a city where to-day I think we are getting posted on water-works, that is, Cincinnati. There we have water-works, but no water. Mr. FitzGerald is not here, and we seem to have discovered it somehow; I dislike to see a man pitched into when he is not present to defend his paper; Mr. FitzGerald's general deductions probably are not altogether free from the errors which follow too broad an application of averages, for there is a rule that "averages will lie sometimes," but I think he has given some tables which are of great value. The tables made from the reports of all the various companies are very interesting. Of course in some cities where they have combined systems, such as Boston and some other places, he may be mistaken in his conclusions, but any one willing to make proper allowance for the varying conditions governing the operation of the water-works of each of these cities, can take these tables and make his own deductions. I think this paper is worthy of some credit, and for the tables he has given us Mr. FitzGerald certainly deserves our thanks.

The Chair (William Metcalf, M. Am. Soc. C. E.).—If there is no further discussion I want to mention one matter that is to me of great interest. It always did seem to me that it was extremely dangerous for a town to depend upon a pump if it was possible to get a reservoir.

We have had at times a great deal of trouble from the floods in the Allegheny River, and a couple of years ago I thought I would make a great improvement. I had the Philadelphia Company send their dredge up and dredge a place some 10 or 15 feet deep in the bed, and near the mouth of the Allegheny River. I then had a heavy timber crib built in the space thus dredged, and sunk our suction pipes into this crib. We got a beautifully clear water, and thought we had done a very great thing, but in a few days our whole concern was up in arms. A great many complaints were made, and they told me they could not get the boilers clean. The man in charge of the boilers said if he had to use

that water he would give up the job because he knew the result would be an explosion. Of course I thought they were simply pumping out a little loose sand, but I had Professor Langley take up the matter and analyze the water to see if there was any real cause for trouble. The Allegheny River water is a very soft, delicious water, and we found that we had in that short distance of 12 or 15 feet struck a sub-river of lime-water some 12 feet below the Allegheny, which contained thirteen times as much sediment as the muddiest river-water we could get from a dirty flood stage in the river. So we were obliged to destroy the crib at considerable expense.

J. Leland FitzGerald, M. Am. Soc. C. E.—It was my intention in the foregoing paper to confine the arguments to the scope of the title, that is, which class of systems is the cheapest based on the data at hand. If no reliance can be placed on the latter, no general conclusions can be drawn.

As to the average life of cast-iron mains, I confess that I have been able to procure no data on the subject. In Schenectady the mains were originally of cement-lined wrought-iron and were laid in 1870. They have almost entirely been replaced by cast-iron, and all extensions since that date have been of the latter material. Many of these have been relaid but, as much on account of insufficient size as of growing weakness of material.

From the conflicting facts as to the effects of storage on water, the subject can hardly be called settled. Mr. L. J. LeConte, in a paper read before the American Water Works Association, discusses the effect of storage of surface waters on a large scale on the Pacific Coast. In addition to this, nearly every report from towns having a reservoir system, speaks of there being trouble at some time or other from low growths. Rain water is stored in some Mexican towns in large quantities and in covered reservoirs. The water at the end of the dry season grows so foul that strangers drink it with the greatest repugnance.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

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(Vol. XXIV.—April, 1891.)

DETERMINATION OF THE STRESSES IN ELASTIC SYSTEMS BY THE METHOD OF LEAST WORK.

By WILLIAM CAIN, M. Am. Soc. C. E.

A new method of ascertaining the stresses in elastic structures, by means of the principle of Least Work, has been elaborated by Castigliano, in his "Théorie de l'Equilibre des Systémes Élastiques" (Turin, 1879), who claims to have given the first complete demonstration of the theorem of least work, though several authors have touched upon the subject from 1818 to the present time.

The method is found to be of very general application to all structures in which the laws of elasticity have to be considered in finding the stresses; as in every kind of beam or arch, trusses of any shape with superfluous members and all systems where there is any continuity in the members or where there is not free play at the joints, as in nearly all roof or bridge trusses.

It further offers an exact method by which we can ascertain the limit of error made in our ordinary approximate computations (which apply only to articulated systems, free to move at all the joints), and thus exposes some of the unknown errors which are usually included in our

"factor of safety," though it has more appropriately been termed our "factor of ignorance."

In the first nine articles that follow, the theorems of "least work" and "deflection" are deduced by aid of the principle of "virtual velocities as applied to framed structures," as developed by Mohr, Maxwell and others. The rather obvious relation between the two has, doubtless, been hitherto observed, though the writer has not met with it anywhere.

The demonstrations of Castigliano are very direct and elegant; but the method of virtual velocities, which is valuable in itself, leads so easily and unmistakably to his conclusions that it was preferred to his demonstrations, particularly as it leaves no doubt as to the exact interpretation of results. A *résumé* of the method of virtual velocities as applied to certain framed structures was given by Prof. George F. Swain in the *Journal of the Franklin Institute* for February, March and April, 1883, to which the writer is pleased to acknowledge his indebtedness.

In Articles 10, 11, 12, that follow, are given certain essential theorems (taken mainly from Castigliano) necessary to put the reader, in the briefest time, in possession of the general method leading to the applications. The theory of arches is then carefully developed in Article 13, and pains have been taken to make it as clear and simple as possible.

As Castigliano's book is accessible to engineers, it was thought best to refer to it for the numerical illustrations of the theory, which are given there in great number and variety. Some of the methods and results are briefly stated in Article 14, however, referring to "Composite Structures," and a comparison instituted between these correct results and those given by approximate methods, which should command careful attention. In fact, such comparisons should be the main object in view in cases where the exact and approximate methods do not differ too widely, for although the method of least work leads to a direct and systematized method of procedure that is easily acquired, yet the numerical applications are long, and will hardly come into daily use for such cases. Where the exact and approximate methods differ widely, the method of work should be used.

Section 1.

As preliminary to the treatment of elastic systems, we shall first state the well-known relation between the stress and the change of length of a prismatic bar subjected to simple tension or compression in the

direction of its length, and then deduce an expression for its elastic work of deformation during the change of length.

If we call a the length of the bar, ω its cross-section, e the modulus of elasticity and λ its change of length under the stress s, then we know from experience that when the resultant stress acts along the axis and the limit of elasticity has not been exceeded, that,

$$\lambda = \frac{as}{e\omega} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

If, for the sake of brevity, we put $c = \frac{a}{e\omega}$, we have the alteration in length given by the following expression:

$$\lambda = cs \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where several bars are considered at the same time, we shall designate the corresponding quantities that enter in (1) and (2) by proper subscripts.

Now, if the bar lengthens or shortens the amount λ by the action of a load P acting in the direction of its axis, which gradually increases from O to its greatest value P, the stress likewise increases gradually from O to its greatest value s, and at any instant the stress is exactly equal to the load. Then if successive values of s, beginning with O, are so taken that each increment of stress corresponds to equal changes of length ($d\lambda$), we have the total work of deformation equal to the limit of the sum,

$$\sum s d\lambda = \sum \left(\frac{e\omega}{a} \lambda d\lambda \right)$$

between the extreme valves $\lambda = O$ and $\lambda = \lambda$.

$\therefore$ The work of deformation is equal to,

$$\frac{e\omega}{a} \int_{o}^{\lambda} \lambda d\lambda = \frac{e\omega}{a} \frac{\lambda^2}{2} = \tfrac{1}{2} \frac{a}{e\omega} s^2 = \tfrac{1}{2} s\lambda \quad \ldots\ldots\ldots (3)$$

or since load $P = s$, work $= \frac{1}{2}$ load $\times$ change of length. For a suddenly applied load P, causing a change of length λ^1 and maximum stress s, the work of the load is $P\lambda^1$, and since the stress gradually increases from O to s, the work of deformation by (3) is $\frac{1}{2}s\lambda^1$, and since these are equal, $s = 2P$, or the maximum stress, is double the load, hence by (1) the change of length is double that for a gradually applied load. After a series of oscillations this change ultimately becomes that due to a gradually applied load, and s reduces to P.

Section 2.—The Law of Virtual Velocities.

If the point of action of a force is supposed displaced through an indefinitely small distance, the projection of this distance on the direction of the force is called its virtual velocity.

If the direction of this projection, counting from the original point of action of the force, is in the direction of the force, *i. e.*, if the force moves forward as it is directed, the virtual velocity will be called plus; if the direction of the projection of the displacement is opposed to that of the force or if the force is moved backward or contrary to the direction in which it tends to go, then the virtual velocity will be called minus. For the present all forces will be regarded as plus.

With the above conventions assumed, the principle of virtual velocities consists in this: that if any number of forces, at one or more points of a rigid body, be in equilibrium, then if the body is supposed to receive an indefinitely small displacement, the algebraic sum of the products of each force into its virtual velocity is equal to zero.

The product of a force by the distance through which it is moved, counted along its direction, is called the work of the force, which is positive or negative according as the virtual velocity is positive or negative.

Section 3.

As trusses with superfluous bars will be considered in what follows, it is well, likewise, to recall, that where the figure of a truss has more lines than are necessary to strictly define its form, *i. e.*, to fix its apices, when the length of sides are given in order, the extra sides are said to be "superfluous."

The relation between the least number of sides m, or the number of "necessary" bars in a truss, and the number of joints or apices n, for strictly defining the form of a figure of invariable form, is easily arrived at.

Thus, for plane figures, assume the position of one side, thus fixing the two apices at its ends. From these apices we can fix another with two new sides, then another with two new sides from two apices previously fixed, and so on; therefore, to each of the $(n - 2)$ joints other than the first two, corresponds two sides, so that the total number of necessary sides $m = 2\,(n - 2) + 1 = 2n - 3$. If the number of sides exceeds $(2\,n - 3)$, the extra number are "superfluous" to strictly define the

form. A less number will give a figure that can change its shape without changing the lengths of its sides.

For figures in space, we select three sides in position to fix three apices, then to fix each new apex, we need three sides or distances from three apices already fixed. Therefore it takes three sides for each apex, except the first three, which required only three in all. Therefore, $m = 3\ (n - 3) + 3 = 3n - 6$, which gives the least number of sides to constitute a figure of invariable form in space.

Now, in any truss, without superfluous bars, constituting a figure of invariable form, statics can determine the stresses in all the members; for at each of the n joints, for trusses in one plane, we can write two equations, expressing the law that the sum of the horizontal as well as of the vertical components of the external forces and stresses in the bars, meeting there, are separately equal to zero. This gives $2n$ equations, but these reduce to $(2n - 3)$ independent equations for trusses in one plane, or the exact number of bars, since there are three necessary equations between the equilibrated external forces, indicating that the sum of their horizontal components is zero, the sum of their vertical components is zero, and the sum of the moments of the forces about any point in the plane of the forces, is zero.

For trusses having any position in space, statics gives at each joint three equations, expressing that the sum of the components of external forces and stresses there, parallel to three axes, are separately equal to zero, giving in all $3n$ equations; but we have now 6 equations of equilibrium between the external forces alone, hence the number of independent equations between the stresses reduces to $(3n - 6)$ or the number of the bars.

In both cases, then, of trusses in one plane or having any position in space, we have only as many equations as bars, when there are no superfluous members, so that the stresses in the bars can be found. If the truss, therefore, has superfluous bars, statics will furnish too few equations by the number of superfluous bars.

Section 4.—Application of the Principle of Virtual Velocities.

Let us consider the frame, Fig. 1, lying in one plane, free to move at the joints, with smooth supports and having one superfluous bar, say CD, since $m = 6$ exceeds $2n - 3 = 8 - 3 = 5$, by one.

Here statics alone cannot determine the stresses, giving too few equations by one:

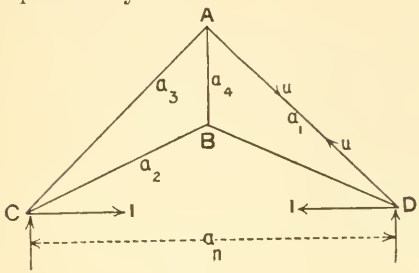


Fig. 1

Let us first suppose no load on the truss, that bar CD is removed, and that two opposed forces each equal to unity, act toward each other at C and D along the line CD.

These forces will generally cause stresses in the remaining bars, and reactions at the supports, unless they are smooth as assumed; that can be computed by statics alone. Call the stress induced by the forces 1 acting along CD in bar AD, u and the change of length of AD, Δl.

If the forces unity cause tension in AD, we can suppose the bar AD removed if we replace its action by two forces each equal to u acting toward each other at A and D. The system with the bars CD and AD removed and the forces 1 and u applied as shown, constitutes a system in equilibrium.

Now from whatever cause, suppose the distance CD to be increased an amount Δp^1 due to an increase Δl in AD alone, the remaining bars retaining their original lengths. The virtual velocities of forces 1 and u are both negative as by Section 2, the forces are moved contrary to their directions. Therefore by the principle of virtual velocities,

$$-1\,\Delta p^1 - u\Delta l = 0 \qquad (4)$$

The value of the elongation Δp^1 from this equation is $(-u\Delta l)$, so that the points C and D must approach each other when A and D recede from each other, as would happen when u is tension. It is convenient, however, throughout, when we do not know the character of the stresses beforehand, to assume the stresses in all the bars to be tensions, and the corresponding change of length between any two apices to be an increase. On solving the resulting equations to be presently deduced, the true character of the stresses will depend upon the sign of the resulting stress, plus for tension (as assumed), minus for compression.

If the two forces unity, acting along CD, cause compression in the bar AD, before it it supposed removed, then the two forces u at A and D that replace the action of the bar AD upon the rest of the truss,

will act in the opposite directions to those shown in the figure, and the term $(-\ u\Delta l)$ in (4) becomes $(+\ u\Delta l)$ and $\Delta p^1 = +\ u\Delta l$ is an elongation as assumed.

We see, therefore, that u, in equation (4), is to be taken as + or — according as it represents tension or compression.

Now, as there has been no restriction whatever as to the numerical value of Δl, it can be taken equal to the actual change of length of bar AD due to the loading assumed for the complete truss, bars AD and CD included. Hence, if we call a_1 the length of bar AD, e_1 its modulus, ω_1 its cross-section and s_1 the actual stress in it, due to the actual loading on the complete truss, we have:

$$\Delta l = \frac{a_1\, s_1}{e_1\, \omega_1} = c_1\, s_1$$

So that equation (4) becomes

$$-1.\ \Delta p^1 - u\,\frac{a_1\, s_1}{e_1\, \omega_1} = 0,$$

in which if s_1 is tension, it is to be given the + sign, if compression the — sign; since in the first case Δl is an elongation as assumed, and in the second case a shortening, so that the principle of virtual velocities, as illustrated by equation (4), obtains with the conventions adopted as to signs, the second term of the first member changing sign with s_1. The equation is therefore perfectly general, and it is only necessary to pay proper attention to the signs of the stresses and displacements, to correctly interpret the results.

We can now write an equation similar to the last one above for the remaining bars of the truss, by considering the change in length in CD due to each bar in turn, supposed elastic, the remaining bars being temporarily supposed inelastic, since in the truss without the one superfluous bar CD, any bar can change length without causing any change of length in the other bars.

Therefore regarding all the bars as elastic we have the total change of length of CD (plus for an elongation, minus for a shortening) due to the changes of length of all the bars other than CD, equal to

$$\Delta p = -\sum u\,\frac{as}{e\omega} \qquad (5)$$

But this change of length Δp in the distance CD, due to the changes in length of the other bars, resulting from the assumed loading of the complete truss, is exactly equal to the real change of length in the super-

fluous bar CD, due to the same loading, since the final lengths and positions of the other bars, completely fix the new length CD of the superfluous bar after strain, in consequence of the necessary geometrical relation between the lengths (Section 3).

Therefore, if s_n is the stress caused in the superfluous bar by the loading, and a_n, e_n and ω_n represent the length, modulus and cross-section respectively, we have,

$$\Delta p = \frac{a_n\, s_n}{e_n\, \omega_n},$$

whence,

$$\frac{a_n s_n}{e_n \omega_n} + \sum u \frac{as}{e\omega} = 0 \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

the sum being extended to all the bars other than CD or the "necessary bars" as they will be called, as this number of bars is necessary to define the form of the truss, any other bars being superfluous to that end.

If we designate generally by y, the stress caused in any one of the necessary bars by the loading assumed, when the superfluous bar is removed, which stress can be computed by statics alone (as also can u, the stress caused by forces 1 acting toward each other in the line of the removed superfluous bar, whose real stress is s_n), then by the principle of the superposition of effects, the actual stress in the necessary bar considered is,

$$s = y + u\, s_n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

On substituting such values for s in equation (6) for all the necessary bars, we have an equation in which the only unknown quantity is s_n (the stress in the superfluous bar), which can thus be found, and afterward the stresses in the remaining bars can be determined by aid of equation (7).

Strict attention must be paid to the signs of the stresses u (tension +, compression —) in equations (5) and (6) as already mentioned, whence the resulting sign of s_n and of the stresses in the necessary bars will indicate the character of the actual stresses in all the bars due to the assumed loading.

If we term the $n-1$ bars, to be numbered 1, 2, ... $(n-1)$ on the diagram, the necessary bars, then the nth bar will be the superfluous one, and designating by the proper subscripts the constants a, e, ω and u, pertaining to each bar, equation (6) can be written as follows, for any truss whatsoever, having but one superfluous bar:

$$u_1 \frac{a_1 s_1}{e_1 \omega_1} + u_2 \frac{a_2 s}{e_2\, \omega_1} + \ldots + \frac{a_n s_n}{e_n \omega_n} = 0 \ldots\ldots\ldots\ldots (8)$$

where $s_1, s_2 \ldots$ have values given by expressions of the form shown in equation (7). It is well to observe that the demonstration given is equally correct, whether the truss is supposed in one plane or not.

Example.—A simple example will illustrate the working of the method.

In Fig. 2, the frame is supposed to consist of three bars) 1, 2 and 3), whose lengths are a_1, a_2, a_3, respectively, the bar AB being taken as the superfluous one. The distance $BC = CD = b$; the actual stresses due to load W at A are s_1, s_2, s_3, in bars 1, 2, 3, the moduli e_1, e_2, e_3, and the cross-sections ω_1, ω_2. ω_3, respectively.

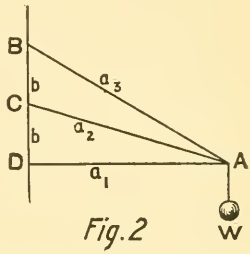


Fig. 2

Now suppose the bar AB removed, and that forces equal to unity act towards each other at A and B, the weight W being removed. Calling the stresses induced in bars 1 and 2, by these forces unity, u_1, and u_2, we have (treating the stresses as tensions until ascertained), on balancing vertical and horizontal components separately at the apex A,

$$1\,\frac{2b}{a_3} + u_2\,\frac{b}{a_2} = 0$$

$$1\,\frac{a_1}{a_3} + u_2\,\frac{a_1}{a_2} + u_1 = 0$$

Whence—

$$u_2 = -\,\frac{2a_2}{a_3},\ u_1 = \frac{a_1}{a_3}$$

Similarly, calling Y_1 and Y_2 the stresses caused in bars 1 and 2 by weight W, when bar AB is supposed removed, we find,

$$Y_1 = -\,W\frac{a_1}{b},\ Y_2 = W\frac{a_2}{b}$$

Therefore, the actual stresses in bars 1 and 2 are—

$$s_1 = y_1 + u_1 s_3 = -\,W\,\frac{a_1}{b} + \frac{a_1}{a_3}\,s_3$$

$$s_2 = y_2 + u_2\,s_3 = W\frac{a_2}{b} - \frac{2a_2}{a_3}\,s_3$$

We can at once substitute these values in equation (8) and solve for $s_n = s_3$ and then find s_1 and s_2 from the eqnations above; we have therefore

$$u_1\,\frac{a_1\,s_1}{e_1\,\omega_1} + u_2\,\frac{a_2\,s_2}{e_2\,\omega_2} + \frac{a_3\,s_3}{e_3\,\omega_3} = 0,$$

from whence by substitution and reduction we obtain finally, putting $e_1\,\omega_1 = e_2\,\omega_2 = e_3\,\omega_3$ for simplicity,

$$s_3 = W \frac{a_3}{b} \cdot \frac{a_1^3 + 2a_2^3}{a_1^3 + 4a_2^3 + a_3^3}.$$

This stress is always +, so that bar 3 is always in tension as assumed. The stresses in bars 1 and 2 can now be found as indicated, and their signs will designate their character.

Section 5.—The Principle of Least Work.

Let us consider a frame of n bars, free to move at the joints, having one superfluous bar. Number the bars consecutively from 1, so that the nth bar is the superfluous bar.

Designating, as in the preceding article, by the proper subscripts, the constants a, e, ω and u pertaining to each bar, and writing for brevity,

$$\frac{a_1}{e_1\,\omega_1} = c_1, \quad \frac{a_2}{e\,\omega_2} = c_2 \ldots\ldots;$$

then equation (8) can be written,

$$u_1\,c_1\,s_1 + u_2\,c_2\,s_2 + u_3\,c_3\,s_3 + \ldots\ldots + c_n s_n = 0 \ldots\ldots\ldots\ldots (9)$$

We likewise have,

$$\left.\begin{array}{lll} s_1 = Y_1 + u_1\,s_n & \therefore \dfrac{ds_1}{ds_n} = u_1 \\ s_2 = Y_2 + u_2\,s_n & \therefore \dfrac{ds_2}{ds_n} = u_2 \\ \ldots\ldots\ldots\ldots\ldots\ldots & \ldots\ldots\ldots\ldots\ldots \\ s_{n-1} = Y_{n-1} + u_{n-1}\,s_n & \therefore \dfrac{ds_{n-1}}{ds_n} = u_{n-1} \end{array}\right\} \ldots\ldots (10)$$

where $\frac{ds_1}{ds_n}$, $\frac{ds_2}{ds_n}$ ...., are the derivatives with respect to s_n of s_1, s_2 ...., s_{n-1}.

As Y_1, Y_2 .... Y_{n-1} are not functions of s_n, they disappear in the differentiation.

Therefore (9) can be written,

$$c_1\,s_1\,\frac{ds_1}{ds_n} + c_2\,s_2\,\frac{ds_2}{ds_n} + \ldots\ldots + c_{n-1}\,s_{n-1}\,\frac{ds_{n-1}}{ds_n} + c_n\,s_n = 0 \ldots (11)$$

which is the differential co-efficient, with respect to s_n, put equal to zero, of the expression,

$$F = \tfrac{1}{2}\,[c_1\,s_1^2 + c_2\,s_2^2 + \ldots\ldots + c_{n-1}\,s^2_{n-1} + c_n\,s^2_n],$$

or its equivalent,

$$F = \tfrac{1}{2}\left[\frac{a_1}{e_1\,\omega_1}\,s_1^2 + \frac{a_2}{e_2\,\omega_{2-1}}\,s_2^2 + \ldots\ldots + \frac{a_{n-1}}{e_{n-1}\,\omega_{n-1}}\,s^2_{n-1} + \frac{a_n}{e_n\,\omega_n}\,s^2_n\right] (12)$$

which by Section 1 represents the total work of deformation of all the bars that constitute the complete truss under the assumed loading. We therefore conclude, for a frame with one superfluous bar, that *the stresses of the bars after deformation are such as render a minimum the work of deformation of the system, having regard to the laws of statics.*

In order to make use of equation (11) to determine the stress s_n, from which s_1, s_2 .... can be found from (10), we must express the other stresses s_1, s_2 .... s_{n-1} as functions of s_n, so as to effect the differentiation involved. When the values of s_1, s_2 .... are given, as in (10), this is quickly done, as Y_1, Y_2 ...., not being functions of s_n, disappear in the differentiation; but if the values of s_1, s_2 .... are first found as functions both of s_n and some of the other stresses, these last are functions of s_n, and must be so expressed before the differentiation can be effected.

It will be observed that equation (11) is identical with equation (8) of Section 4, so that the solution is the same for any special case.

We shall now give two examples to show the application of the principle of least work.

Example I.—The truss is shown in Fig. 1, Section 4. Call $2a_1$ the length of span $=2\,000$, $a_2=1\,118$, $a_3=1\,414$, $a_4=500=$ half the height of truss, and suppose the truss loaded at the upper apex with 2 tons, giving vertical reactions of 1 ton each, with a supposed perfect roller under one end. The stress under this load in bar CD will be called s_1, in bars CB or BD s_2, in bars AC or AD s_3, and in bar AB s_4, the bars symmetrical with respect to the center having the same stress.

Then regarding all stresses as tensions, we can deduce the following equations by noting that the sum of the horizontal and vertical components of the forces acting at C are separately equal to zero, and by balancing the vertical components of the stresses in the bars meeting at B.

$$1+\frac{500}{1\,118}s_2+\frac{1\,000}{1\,414}s_3=O \qquad (1)$$

$$s_1+\frac{1\,000}{1\,118}s_2+\frac{1\,000}{1\,414}s_3=O \qquad (2)$$

$$2\,\frac{500}{1\,118}s_2-s_4=O \qquad (3)$$

From these three equations we derive :

$$s_1=\left(1-\frac{500}{1\,118}s_2\right), \qquad \therefore \frac{ds_1}{ds_2}=-\frac{500}{1\,118}$$

$$s_3 = -\left(\frac{1\,414}{1\,000} + \frac{1\,414}{2\,236}\, s_2\right), \quad \therefore \frac{ds_3}{ds_2} = -\frac{1\,414}{2\,236}$$

$$s_4 = \frac{1\,000}{1\,118}\, s_2, \qquad \therefore \frac{ds_4}{ds_2} = \frac{1\,000}{1\,118}$$

We have thus expressed s_1, s_3, s_4, in terms of s_2, though any other bar than BC could have been selected as the superfluous bar with equal propriety, the ease of elimination being the chief thing to consider. Now, if for simplicity, we regard all the bars as having the same modulus of elasticity and cross-section, we have the total elastic work of deformation after strain, for all the bars of the truss,

$$L = \frac{1}{2e\omega}\left[2a_1\, s_1^2 + 2a_2\, s_2^2 + 2a_3\, s_3^2 + a_4\, s_4^2\right],$$

which must be a minimum; therefore putting its first differential coefficient, with respect to s_2, equal to zero, we have,

$$2a_1\, s_1 \frac{ds_1}{ds_2} + 2a_2\, s_2 + 2a_3\, s_3 \frac{ds_3}{ds_2} + a_4 \frac{ds_4}{ds_2} = 0$$

On substituting the above values for s_1, s_3, s_4, $\frac{ds_1}{ds_2}$, $\frac{ds_3}{ds_2}$, $\frac{ds_4}{ds_2}$, we readily deduce from the resulting equation of the first degree as to s_2,

$$s_2 = -.39 \text{ tons, or } .39 \text{ tons compression,}$$

whence, substituting in the above values for s_1, s_3, s_4, we find,

$$s_1 = +1.17,\ s_3 = -1.17,\ s_4 = -0.35.$$

For span invariable (no roller) the term $2a_1\, s_1^2$ drops out of the value of L as the horizontal bar is no longer in action, and the abutments supply horizontal forces acting inward, which may be termed s_1, so that equations (1), (2) and (3) still hold on this supposition. As the work of the bars in action must be a minimum, as before $\frac{dL}{ds_2} = O$, which gives us,

$$s_2 = -.67 \text{ ton} = 0.67 \text{ ton compression.}$$

On substituting this value, in the expressions for s_1, s_3, s_4, we find,

$s_1 = +1.306$ tons = horizontal component of reaction,

1 ton = vertical component of reaction,

$s_3 = -1.00$ ton (compression),

$s_4 = -0.60$ ton (compression).

Compare with the solution given on page 330 of *Van Nostrand's Magazine* for October, 1882, by another method.

Example II.—In the truss shown in Fig. 3, if we suppose the diagonals to be equally capable of taking tension or compression, the truss

has one superfluous bar, as $m = 10$ is greater by 1 than $2n - 3 = 2 \times 6 - 3 = 9$. Let the lengths and stresses be designated as in the figure, and for simplicity, suppose a common modulus and cross-section for the bars included in the investigation below. If the upper segments of the chord are taken equal, the right reaction $= Q = \frac{1}{3}P$, the left reaction $= \frac{2}{3}P$. From these we can at once derive the stresses in the outer triangles so that they can be treated as external forces and we can confine our investigation to finding the stresses in the six remaining bars of the central portion A, B, C, D.

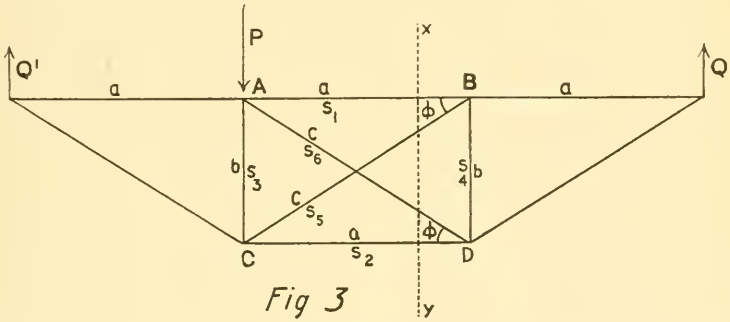


Fig 3

Statics can furnish five independent equations, giving the relations between the stresses in the six bars, and the principle of least work will furnish the remaining equation needed.

Thus, suppose a section $x\ y$, cutting the four bars shown, and that the part of the truss to the right of the section is in equilibrium under the action of the stresses in the four bars and of the right reaction Q. Then, calling the angle $ABC = \varphi$, and taking moments about B, regarding all stresses as tensions, we have,

$$(s_2 + s_6 \cos.\ \phi)\ b - Qa = 0 \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Similarly taking moments about D,

$$(s_1 + s_5 \cos.\ \phi)\ b + Qa = 0 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Next, balance the vertical components of the stresses at the section $x\ y$, with the reaction Q,

$$(s_5 - s_6) \sin.\ \phi - Q = 0 \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Also, since the sum of the vertical components of the stresses meeting at the point B is zero,

$$s_5 \sin.\ \phi + s_4 = 0 \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Similarly for the point A,

$$s_6 \sin.\ \phi + s_3 + P = O \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Now, treating AD, as the superfluous bar, we must express the other stresses in terms of s_6, which is easily done by elimination in the preceding equations, and then the derivatives given are easily found.

$$s_1 = -\left(\frac{Qa}{b} + Q \cot.\ \phi + s_6 \cos.\ \phi\right) \quad \therefore \frac{ds_1}{ds_6} = -\cos.\ \phi$$

$$s_2 = \frac{Qa}{b} - s_6 \cos.\ \phi \quad \therefore \frac{ds_2}{ds_6} = -\cos.\ \phi$$

$$s_3 = -(P + s_6 \sin.\ \phi) \quad \therefore \frac{ds_3}{ds_6} = -\sin.\ \phi$$

$$s_4 = -(Q + s_6 \sin.\ \phi) \quad \therefore \frac{ds_4}{ds_6} = -\sin.\ \phi$$

$$s_5 = \frac{Q}{\sin.\ \phi} + s_6 \quad \therefore \frac{ds_5}{ds_6} = 1$$

The total elastic work due to deformation of the six bars is,

$$L = \frac{1}{2e\omega}\left[(s_1^2 + s_2^2)\, a + (s_3^2 + s_4^2)\, b + (s_5^2 + s_6^2)\, c\right]$$

Placing the derivative, with respect to s_6, equal to zero, we deduce,

$$\left(s_1 \frac{ds_1}{ds_6} + s_2 \frac{ds_2}{ds_6}\right) a + \left(s_3 \frac{ds_3}{ds_6} + s_4 \frac{ds_4}{ds_6}\right) b + \left(s_5 \frac{ds_5}{ds_6} + s_6\right) c = O$$

On substituting the above values, and solving for s_6, we derive, after putting $\sin.\ \phi = \frac{b}{c}$, $\cos.\ \phi = \frac{a}{c}$, $\cot.\ \phi = \frac{a}{b}$, $\operatorname{cosec.}\ \phi = \frac{c}{b}$ and $Q = \frac{1}{3} P$,

$$s_6 = -\frac{Pc}{6b} \frac{a^3 + 4b^3 + c^3}{a^3 + b^3 + c^3};$$

from whence, by aid of the previous equations, we can find all the other unknown stresses.

In case the sections and moduli are not taken equal for the six bars, the solution is equally direct, but the value of s_6 is given by a much more complicated expression.

As is well known, American engineers generally construct the diagonals so that they can take but one kind of stress; therefore, as there is no superfluous bar under strain, statics alone can determine the stresses and the previous method is not needed.

As already mentioned, the solutions just given are identical with the method of section 4, so that so far there is no saving in labor in using the method of least work; but the rule is so simple and the principle so interesting from a scientific point of view, that possibly many will prefer it to the method on which we have founded it.

It is easily seen from these examples that the values of u of Section 4 may be obtained, as can the values of $\frac{ds}{ds_n}$ from the values of s above, by making the loading on the truss zero and $s_n = 1$, or *vice versa* $\frac{ds}{ds_n} = u$ can be found as in Section 4, whichever way appears to offer the simplest solution.

Section 6.—Truss with any Number of Superfluous Bars.—Demonstration of the Theorem of Least Work.

Let us suppose now that we have a system of $(n-1)$ bars, numbered consecutively 1, 2, ...$(n-1)$, that we shall term "system N" of necessary bars, and in addition three superfluous bars numbered n, $(n+1)$, and $(n+2)$ respectively; so that the complete truss contains $n+2$ bars, of which the first $n-1$ are sufficient to fully define the form.

Let us use the notation of Section 5, extending it to the case of the extra superfluous bars by the use of the proper subscripts.

We shall give in this article, besides, the following meaning to the quantities below:

$Y_1, Y_2, Y_3, \ldots\ldots \lambda_{n-1}$ = stresses, in bars 1, 2, ... $(n-1)$, of a frame supposed to consist of necessary bars alone (system N) subjected to the assumed loading.

$u_1, u_2, \ldots\ldots\ldots\ldots u_{n-1}$ = stresses in bars 1, 2, ...$(n-1)$ of "system N" alone, by forces unity acting toward each other from either end of the original position of superfluous bar n, the superfluous bars being supposed removed, however.

$V_1, V_2, \ldots\ldots\ldots\ldots V_{n-1}$ = stresses in bars 1, 2, ...$(n-1)$ of a frame supposed to consist of system N alone, caused by forces unity acting toward each other from the apices at the ends of superfluous bar $(n+1)$, all the superfluous bars being removed.

$v_1, v_2, \ldots\ldots\ldots\ldots v_{n-1}$ = same when forces unity act along original position of superfluous bar $(n+2)$.

The stresses Y, u, v and r can all be found by the laws of statics alone, without the aid of the theory of elasticity.

We shall further designate by,

$$\Delta a_n,\ \Delta a_{n+1},\ \Delta a_{n+2},$$

the amounts by which the apices at the ends of bars n, $(n+1)$, $(n+2)$ recede from each other under the actual final stresses and by,

$$\lambda_n,\ \lambda_{n+1},\ \lambda_{n+2},$$

the amounts by which bars n, $(n+1)$, and $(n+2)$ were too short to fit into the frame of necessary bars alone when under no stress, from temperature changes or actual misfit.

First consider the system with the superfluous bars removed and forces 1 acting toward each other along line of superfluous bar n.

Then by the principle of virtual velocities, as in section 4, we have, since $\Delta a_n + \lambda_n = c_n s_n$, or $\Delta a_n = -(\lambda_n - c_n s_n)$,

$$-u_1 \Delta a_1 - u_2 \Delta a_2 - \ldots - u_{n-1} \Delta a_{n-1} + (\lambda_n - c_n s_n) = O,$$

where Δa_1, Δa_2, ... $(c_n s_n)$, are the real changes of length of bars 1, 2, ...n in the complete structure under the final loading; for the real change of length $(c_n s_n)$ of the superfluous bar n is of a necessary consequence of the real changes of length of the necessary bars alone, and can therefore be found without knowing the changes of length in the other superfluous bars at all. In fact when the "system N" of necessary bars is built up from the final lengths of the necessary bars alone, the changes of length $c_n\ s_n$, $c_{n+1}\ s_{n+1}$, $c_{n+2}\ s_{n+2}$, and consequently the new lengths of the three superfluous bars, must correspond exactly to the corresponding new lengths, thus fully determined from the frame of necessary bars alone after stress.

If we next consider system N alone, acted on by forces 1, directed toward each other, along line of superfluous bar $(n+1)$, we have, since $c_{n+1}\ s_{n+1}$ is the stretch of bar $(n+1)$ (which must equal that deduced from a consideration of the frame of necessary bars alone after deformation), and $\Delta a_{n+1} = -(\lambda_{n+1} - c_{n+1}\ s_{n+1})$,

$$-r_1 \Delta a_1 - v_2 \Delta a_2 - \ldots - v_{n-1} \Delta a_{n-1} + (\lambda_{n+1} - c_{n+1}\ s_{n+1}) = O.$$

Similarly, if we consider only system N acted on by forces 1 acting towards each other along line of superfluous bar $(n+2)$, we have,

$$-r_1 \Delta a_1 - r_2 \Delta a_2 - \ldots - r_{n-1} \Delta a_{n-1} + (\lambda_{n+2} - c_{n+2}\ s_{n+2}) = O.$$

If we substitute for Δa_1 Δa_2 .... the following values, $\Delta a_1 = c_1 s_1$, $\Delta a_2 = c_2 s_2$, ... , we can write the above equations as follows:

$$u_1 c_1 s_1 + u_2 c_2 s_2 + \dots + u_{n-1} c_{n-1} s_{n-1} + c_n s_n - \lambda_n = O \dots\dots\dots (1)$$
$$v_1 c_1 s_1 + v_2 c_2 s_2 + \dots + v_{n-1} c_{n-1} s_{n-1} + c_{n+1} s_{n+1} - \lambda_{n+1} = O \dots (2)$$
$$r_1 c_1 s_1 + r_2 c_2 s_2 + \dots + r_{n-1} c_{n-1} s_{n-1} + c_{n+2} s_{n+2} - \lambda_{n+2} = O \dots (3)$$

We shall now express the final stresses of the necessary bars as follows, as is evidently correct,

$$\left.\begin{array}{l} s_1 = Y_1 + u_1 s_n + v_1 s_{n+1} + r_1 s_{n+2} \\ s_2 = Y_2 + u_2 s_n + v_2 s_{n+1} + r_2 s_{n+2} \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ s_{n-1} = Y_{n-1} + u_{n-1} s_n + v_{n-1} s_{n+1} + r_{n-1} s_{n+2} \end{array}\right\} \dots\dots (4)$$

On substituting these values in the three preceding equations, we have three equations between three unknown quantities s_n, s_{n+1}, s_{n+2}, so that the latter can be found, and on substituting their values in (4), we deduce the values of all the remaining stresses. In fact in any case, we always have as many equations like (1), (2), (3), as superfluous bars, so that it is always possible, no matter what the number of superfluous bars, to find the stresses in all the bars of the complete truss by following this general method.

This gives the solution by the method of virtual velocities. We shall now proceed to deduce the "theorem of least work" for this case.

Let us first note that Y_1, Y_2 .... Y_{n-1} in equations (4) are not functions of s_n, s_{n+1}, s_{n+2}, but that the last three stresses are functions of each other; since any change in any of them (due to varying the sections, say,) will change the stresses in all the other bars of the complete truss, just as equivalent external forces replacing the stresses in one bar, by being supposed to vary, can change the stresses in the remaining bars.

Therefore, if in taking the partial derivatives of s_1, s_2, ..., with respect to s_n, s_{n+1}, s_{n+2}, successively, we regard the stresses in all the superfluous bars as constant, except the one with respect to which the differentiation is effected, the operation is equivalent to considering these "constant" stresses as external forces, which thus are supposed to have the actual, final values of the stresses in the superfluous bars so treated, as constant.

With this understanding, then, we can write the following group of equations derived directly from (4) by differentiation:

$$\left.\begin{array}{lll} \dfrac{ds_1}{ds_n} = u_1, & \dfrac{ds_1}{ds_{n+1}} = v_1, & \dfrac{ds_1}{ds_{n+2}} = r_1 \\ \dfrac{ds_2}{ds_n} = u_2 & \dfrac{ds_2}{ds_{n+1}} = v_2, & \dfrac{ds_2}{ds_{n+2}} = r_2 \\ \cdots\cdots & \cdots\cdots & \cdots\cdots \\ \dfrac{ds_{n-1}}{ds_n} = u_{n-1}, & \dfrac{ds_{n-1}}{ds_{n+1}} = v_{n-1}, & \dfrac{ds_{n-1}}{ds_{n+2}} = r_{n-1} \end{array}\right\} \cdots\cdots (5)$$

Now, substituting these values of u, v and r in equations (1), (2) and (3), we have,

$$c_1 s_1 \frac{ds_1}{d s_n} + c_2 s_2 \frac{ds_2}{ds_n} + \cdots + c_{n-1} s_{n-1} \frac{ds_{n-1}}{ds_n} + c_n s_n - \lambda_n = 0 \cdots\cdots (6)$$

$$c_1 s_1 \frac{ds_1}{ds_{n+1}} + c_2 s_2 \frac{ds_2}{ds_{n+1}} + \cdots + c_{n-1} s_{n-1} \frac{d s_{n-1}}{ds_{n+1}} + c_{n+1} s_{n+1} - \lambda_{n+1} = 0 \cdots\cdots (7)$$

$$c_1 s_1 \frac{ds_1}{ds_{n+2}} + c_2 s_2 \frac{ds_2}{ds_{n+2}} + \cdots + c_{n-1} s_{n-1} \frac{d s_{n-1}}{d s_{n+2}} + c_{n+2} s_{n+2} - \lambda_{n+2} = 0 \cdots\cdots (8)$$

Now, if for convenience, we put the actual elastic work done by system "N" of necessary bars due to the final stresses equal to L,

$$\therefore L = \tfrac{1}{2} [c_1 s_1^2 + c_2 s_2^2 + \cdots + c_{n-1} s_{n-1}^2] \cdots\cdots (9)$$

we see that equations (6), (7) and (8) can be derived by taking successively the partial derivatives, with respect to s_n, s_{n+1}, s_{n+2}, treated as independent of each other, of the expression,

$$L + \tfrac{1}{2} [c_n s_n^2 + c_{n+1} s_{n+1}^2 + c_{n+2} s_{n+2}^2] - [\lambda_n s_n + \lambda_{n+1} s_{n+1} + \lambda_{n+2} s_{n+2}] \cdots\cdots (10)$$

and placing them separately equal to zero.

In words, equation (6) shows us that if we treat the actual stresses in the superfluous bars $(n + 1)$ and $(n + 2)$ as constant external forces, the work of deformation of the remaining bars, diminished by the terms $\lambda_n s_n$, must be a minimum.

Equation (7) shows that the elastic work of "system N," with bar $(n + 1)$ added, minus $\lambda_{n+1} s_{n+1}$, is to be a minimum, the stresses in the other two superfluous bars being treated as constant external forces. Similarly, equation (8) shows that the work of deformation of system N, with bar $(n + 2)$ added, minus $\lambda_{n+2} s_{n+2}$, is to be a minimum, the stresses in the other two superfluous bars being regarded as constant external forces, all the equations being agreeable to the laws of statics.

If λ_n, λ_{n+1}, λ_{n+2} the amounts by which the superfluous bars are too short, are zero, the results can be stated more succinctly as follows:

The stresses of the bars after deformation, are such as render a minimum the work of deformation of the system of necessary bars, combined with one of the superfluous bars at a time, the stresses in the rejected bars being treated as external forces, the results being always agreeable to the laws of statics.

We have been precise in stating this principle, for Castigliano, who deduces his conclusion in a totally different way, states it incorrectly as follows: "The tensions of the bars after deformation, are such as render a minimum the work of deformation of the system, having regard to the $3n - 6$ equations between the tensions of the bars." The equations alluded to are those furnished by statics for each apex of the truss (not regarded as in one plane only), having regard to the conditions that must be fulfilled by the external forces.

It is to be inferred from this statement, which is repeated in several places, that Castigliano holds that the work of deformation of the entire truss must be a minimum, whereas it is only proved for the several partial trusses considered; and in fact in the applications given by that author to "compound systems," the rule or principle, as we have deduced it above, is followed to the letter. Further, the demonstration given by Castigliano leads to the same conclusion.

If we call F the elastic work of deformation of all the bars, including all the superfluous bars, we see that the expression (10) will be represented more simply by

$$F + \Sigma\lambda s,$$

extending the sum Σ only to the superfluous bars. The partial derivatives of this expression with respect to s_n, s_{n+1}, s_{n+2}, respectively placed equal to zero, give the equations (6), (7) and (8) needed; but in taking these partial derivatives s_n, s_{n+1}, s_{n+2}, must be regarded as independent of each other.

Similarly where the frame fits perfectly when not under strain, we have,

$$\frac{dF}{ds_n} = o, \quad \frac{dF}{ds_{n+1}} = o, \quad \frac{dF}{ds_{n+2}} = o$$

or the work of deformation of the whole system is a minimum with respect to s_n, s_{n+1}, s_{n+2} successively, provided we regard these stresses as independent in the differentiation. It gives a simpler rule to work

with when the work of the whole system is found and then differentiated successively as above, but we must not lose sight of the hypothesis that s_n, s_{n+1}, s_{n+2} are regarded as independent.

Section 7.—Derivative of the Work of Deformation with respect to an External Force.—Deflection.

Consider a truss of invariable form, without superfluous bars, and let a force unity act in the direction of and along the line of action of any external force P. Then when the external forces are supposed removed, call u the stress in any bar due to the force unity in question. Let us suppose further that this bar elongates an amount $\Delta l = \frac{as}{e\omega}$, or the exact amount caused by the stress s due to the external forces when in place, and that this elongation alone causes the displacement Δp^1 of force unity in the direction of that force. Then by the principle of virtual velocities, we have, assuming u to be tension,

$$1.\ \Delta p^1 - u\Delta l = 0$$

$$\therefore \Delta p^1 = u\frac{as}{e\omega}$$

If u or s are compressive, they have the minus sign in the above equation, as is evident. Should Δp^1 thus become minus in any case, the displacement will be contrary to the direction of the supposed force unity. Continuing thus to find the displacement of force 1, due to the real change of length of each bar in turn, we have, for the total displacement of the point of application of force unity, acting in the direction of external force P, the known formula,

$$\Delta p = \sum\left(u\frac{as}{e\omega}\right)$$

But since this displacement is that caused by the actual stresses in all the bars due to the original external forces, it must equal the actual displacement of force P along its direction, or the deflection of the truss in the direction of force P.

Now calling X the stress in any bar due to all the loads and their corresponding reactions, when P is omitted, we have the stress in any bar,

$$s = X + uP$$

whence,

$$\frac{ds}{dP} = u,$$

since X is entirely independent of P.

$$\therefore \Delta p = \sum \left(\frac{as}{e\omega} \cdot \frac{ds}{dP} \right) = \frac{d}{dP} \left(\frac{1}{2} \sum \frac{as^2}{e\omega} \right) \ldots\ldots (1),$$

in which s must be replaced by $X + uP$.

We draw from this the important principle, of "the derivative of work," that *if we express the work of deformation of the bars as a function of the external forces, its derivative with respect to one of the forces gives the displacement, in the direction of the force of its point of application.*

Castigliano proves this principle in an entirely different manner and deduces, by its aid, very simply, the principle of least work.

If we call the work of deformation of the system F, it must be borne in mind in applying the principle that when $\frac{dF}{dP} = \Delta p$ is plus, the displacement is in the direction of the force; when minus in a contrary direction. The above demonstration refers only to an articulated frame without superfluous members, in which every external force, being independent, must be represented by a different letter.

Where two equal forces, directed both toward or both from each other along the same line, as in the case of the horizontal thrusts of an arch hinged at the ends at the abutments, are designated by the same letter P, if we call P and P^1 the two forces and F the work of deformation of the truss, then $\frac{dF}{dP}$ and $\frac{dF}{dP^1}$ give the actual displacements of P and P^1 resolved along the direction of the forces, both minus or both plus, according as the motion is opposed to the direction of the force or with it; so that $\frac{dF}{dP} + \frac{dF}{dP^1}$ gives the total relative displacements of P and P^1. Similarly if the superfluous members in any truss are each supposed replaced by two equal forces at either end, each equal to the final stress in the member and designated by the same letter, say P for one of the superfluous bars, then if F represents the work of deformation of the necessary bars, expressed as a function of all the external forces, including there the forces replacing the stresses in the superfluous bars, then as before $\frac{dF}{dP} + \frac{dF}{dP^1}$ gives the total relative displacement of the apices to which the forces P and P^1 $(= P)$ are applied. Now if we regard P^1 as a function of P, the total derivative of F with respect to P, is

$$\frac{dF}{dP} + \frac{dF}{dP^1} \frac{dP^1}{dP};$$

but since $P^1 = P, \frac{dP^1}{dP} = 1$, therefore the total derivative of F with respect to P is $\frac{dF}{dP} + \frac{dF}{dP^1}$, or the total relative displacement of the apics where P and P^1 are applied. Consequently with this interpretation of results, it is not necessary, in the cases supposed, to designate the two equal opposed forces, by different letters.

When any apex of the truss is subjected to any known displacement Δp, the above formula enables us to compute the value of the force P at the apex when statics leaves it undetermined. Thus, if a truss with no surperfluous bars, but not resting on rollers, is subjected to the condition that the yielding of the abutments shall be a certain amount Δp, the horizontal component of the reactions, P, is found by solving the preceding equation $\frac{dF}{dP} = \Delta p$, in which we express the value of the stress in any bar as a function of P as before. As a particular example take the case of

The Braced Arch Hinged at the Springing.

We shall suppose that the truss proper has no superfluous bars, but that it is subjected to the condition that the span is invariable. Call $P = H =$ horizontal component of the thrust at the abutment, the corresponding displacement of H being $\Delta p = O$.

Then calling, as before, $X =$ stress in a bar due to external loads and vertical reactions resulting, H being omitted, we have from equation (1), on substituting the value $s = X + u\,H$,

$$\sum \left(u \frac{aX}{e\omega} + a \frac{u^2 H}{e\omega} \right) = O.$$

The sum Σ being extended to all the bars. In this equation u represents the stress caused in any bar by a force unity at the left abutment, say, acting inward, or with the direction of H, horizontally toward the corresponding reaction unity, acting horizontally inward, at the other abutment. From this equation, in which H is the only unknown quantity, we can at once find the value of H and then the stress in any bar from the equation, $s = X + uH$.

Another method of procedure has already been illustrated for this case of span invariable, in example 1 of Section 5, by simply considering the work in a supposed superfluous horizontal bar to become zero. We get in this way the stress in some bar of the truss from the resulting

equation, and afterward the horizontal thrust and other stresses as readily as by this method.

Braced Arch Fixed at Abutments and Hinged at Middle.

Here we have two unknown forces to determine, the vertical component P and the horizontal component H of the thrust at the crown, or the action of either half of the arch upon the other half. Suppose the thrust of the right half of the arch upon the left half to be directed to the left and upward, so that P is positive upward and H positive to the left in considering the action of the right half upon the left. Call s the actual stress in a bar of the left half due to the final loading, $v =$ stress from force 1 alone at crown acting downward and opposed to direction P, $u =$ stress from force 1 alone acting to right at crown opposed to direction of H, and X the stress caused in any bar of the left half by the actual loading, when P and H are zero, or no thrust at the crown. Designate by s_1, u_1, v_1, X_1, the same quantities for the right half where P and vertical force 1 act downward, and H and horizontal force 1 act to right, at the crown,

$$\therefore s = X - uH - vP.$$

$$s_1 = X_1 + u_1 H + v_1 P.$$

Now, since the vertical and horizontal displacements, downward and to the right respectively, at the crown from the final stresses of the two halves must be separately equal, we have, from the principle above,

$$-\sum\left(\frac{as}{e\omega}\cdot\frac{ds}{dP}\right) = \sum\left(\frac{a_1 s_1}{e_1\,\omega_1}\cdot\frac{ds_1}{dP}\right)$$

$$-\sum\left(\frac{as}{a\omega}\cdot\frac{ds}{dH}\right) = \sum\left(\frac{a_1 s_1}{e_1\,\omega_1}\cdot\frac{ds_1}{dH}\right)$$

in which s and s_1 have the values given above, and the sum Σ in the left members extends to all the bars in the left half, and the sum Σ in the right members extends to all the bars in the right half, of the arch.

These equations can otherwise be written,

$$\sum\left(\frac{as}{e\omega}\,v\right) = \sum\left(\frac{a_1 s_1}{e_1\,\omega_1}\,v_1\right)$$

$$\sum\left(\frac{as}{e\omega}\,u\right) = \sum\left(\frac{a_1 s_1}{e_1\,\omega_1}\,u_1\right)$$

From these two equations, after substituting the values of s and s_1 above, can be found the two unknowns H and P, from which the values of all the stresses can be found from the equations above.

Braced Arch without Hinges.

The braced arch without hinges, and with but one system of triangulation, is shown in Fig. 4. It is plain that with immovable abutments the figure of this arch, *i. e.*, all the apices, can be completely defined by leaving out three bars, say AB, AC and CD; for, on working from the right abutment and fixing each apex by two sides from two apices already established, we finally determine the position of apices B and C, so that with the immovable points A and D of the left abutment, the position of the truss is completely determined without knowing the lengths of the aides AB, AC and CD, which may thus be regarded as superfluous in defining the form of the truss.

Moreover the lengths of the bars so named must exactly fit the distances between the apices B and C so determined and the fixed points A and D at the abutments.

Designate the superfluous bars AB, AC and CD as bars n, $n+1$ and $n+2$ respectively, their actual stresses due to loading by s_n, s_{n+1}, s_{n+2}, and their lengths, moduli and cross-sections, by a, e and ω with the corresponding subscripts.

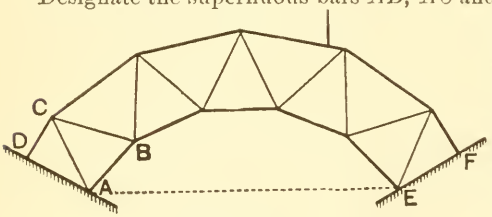


Fig. 4

We shall designate the system composed of the remaining bars as "system N" of necessary bars, as they can alone define the form of the truss. The stress, length, modulus and cross-section of one of the necessary bars will be designated generally by the letters s, a, e and ω, the sums Σ below will refer to the necessary bars alone.

Let us call Y, u, v and r the stresses caused in a bar of the cantilever $EFCB$ of necessary bars alone, respectively by the loading, force 1 acting from B toward A, force 1 acting from C toward A, and force 1 acting from C toward D; which stresses can be found by the laws of statics alone. Then the actual stress in any bar will be given generally by the expression,

$$s = Y + u\,s_n + v\,s_{n+1} + r\,s_{n+2}$$

The work of deformation of the necessary bars alone is,

$$\frac{1}{2}\sum \frac{as^2}{e\omega},$$

in which s has the value just given.

Now, regarding s_n, s_{n+1}, s_{n+2} as constant exterior forces, we have by the principle of the derivative of work above, that the diffential co-efficients of $\frac{1}{2}\sum\frac{as^2}{e\omega}$ with respect to s_n, s_{n+1} and s_{n+2}, successively, will give the displacements of point B in the direction BA, of point C along CA, and of C toward D, respectively. Now as these displacements, added to the changes of length of bars AB, CA and CD, respectively, must equal zero, since the points A and D are immovable, we must have separately,

$$\sum\left(\frac{as}{e\omega}\cdot\frac{ds}{ds_n}\right)+\frac{a_n\,s_n}{e_n\,\omega_n}=0.$$

$$\sum\left(\frac{as}{e\omega}\cdot\frac{ds}{ds_{n+1}}\right)+\frac{a_{n+1}\,s_{n+1}}{e_{n+1}\,\omega_{n+1}}=0.$$

$$\sum\left(\frac{as}{e\omega}\cdot\frac{ds}{ds_{n+2}}\right)+\frac{a_{n+2}\,s_{n+2}}{e_{n+2}\,\omega_{n+2}}=0.$$

If the Σ in the first equation is positive, indicating a shortening of the distance BA, then s_n is negative or compression. Similarly for the others. On substituting the values of s given above, also the values of $\frac{ds}{ds_n}=u$, $\frac{ds}{ds_{n+1}}=v$, $\frac{ds}{ds_{n+2}}=r$, we have three equations between the three unknown quantities s_n, s_{n+1}, s_{n+2}, so that the latter can be found, from which the values of all the remaining stresses can be determined from expressions of the type, $s=Y+u\,s_n+vs_{n+1}+rs_{n+2}$.

Section 8.—Second General Demonstration of the Theorem of Least Work.

A demonstration of the theorem of least work can likewise be given for the case of any number of superfluous bars, by aid of the theory of deflection just demonstrated.

Thus, employing the notation used in the last example, for a truss of any kind with any number of superfluous bars, numbered n, $n+1$, $n+2$, ..., the total elastic work of deformation of all the bars, including the superfluous bars, is,

$$F=\frac{1}{2}\sum\left(\frac{as^2}{e\omega}\right)+\tfrac{1}{2}\frac{a_n\,s_n^2}{e_n\,\omega_n}+\tfrac{1}{2}\frac{a_{n+1}\,a_{n+1}\,s_{n+1}^2}{e_{n+1}\,\omega_{n+1}}+\ldots,$$

in which the sum Σ extends to the necessary bars alone. It is understood, in this and subsequent expressions, that for every value of the stress s in a necessary bar we must substitute expressions of the type given above,

$$s = Y + us_n + vs_{n+1} + \ldots,$$

so that F will be expressed as a function of s_n, s_{n+1}, ...

Now, designating by L the work of deformation of the necessary bars alone, we have,

$$L = \frac{1}{2} \sum \left(\frac{as^2}{e\omega}\right),$$

in which L must likewise be expressed as a function of s_n, s_{n+1}, ..., as before.

Now, consider the superfluous bars n, $n+1$, ..., temporarily removed and replace their action by two forces for each bar, each equal to the stress in the superfluous bar and acting toward each other, as we assume, in framing out equations, that all bars are in tension.

It has been shown above that treating these forces s_n, s_{n+1}, ..., as external forces and independent of each other, that $-\frac{dL}{ds_n}$ represents the increase in distance between the apices at the extremity of bar n, the minus sign being used since the two forces s_n, s_n replacing the tension of the bar, act in the opposite direction to the displacements. Similarly for the other deflections.

Now, since s_n is supposed to equal the actual stress in bar n in the complete structure under the loading, it follows that $-\frac{dL}{ds_n}$, which represents the exact increase of distance between the apices, must equal the elongation of the bar n under the stress s_n when in place; therefore, we must have,

$$-\frac{dL}{ds_n} = \frac{a_n\, s_n}{e_n\, \omega_n},$$

or,

$$\frac{dL}{ds_n} + \frac{a_n\, s_n}{e_n\, \omega_n} = 0$$

We should have a similar expression for each of the superfluous bars, or as many equations as unknown quantities.

Now, each equation of the type just shown can be found by taking the partial derivatives of the expression for F given above, with respect to s_n, s_{n+1}, ..., treated as independent of each other, successively, and placing the results equal to zero. In other words, to determine the unknown stresses we express the work of deformation of the whole system as a function of the stresses in the bars taken as superfluous, then treating these stresses as independent of each other in the differentiation, we express that the work of the necessary bars and one superfluous

bar at a time be a minimum. It is this which constitutes what is called the method of least work.

SECTION 9.—EXTENSION OF THE THEOREMS OF DEFLECTION AND LEAST WORK TO SOLID BEAMS AND TO STRUCTURES WHERE THE PIECES ARE NOT ALL FREE TO MOVE AT THE JOINTS.

In treating of a solid beam, straight or curved, which may of itself constitute a sufficient structure either alone or when in combination with other pieces, we shall assume with Lamé, St. Venant and others, that solids are composed of very small molecules, separated by very small intervals. Further, we shall assume as the result of experience, that—

When the distance between two molecules has been changed by a quantity very small in relation to the distance between their centers, from the application of exterior forces, there is developed along the line of these centers, an elastic force proportional to the change of length of this distance, which is attractive or repulsive according as the two molecules are made to recede from or approach each other.

The law being admitted, we see that all the bodies and all elastic systems whatsoever can be regarded as articulated systems, and consequently enjoy the properties of such systems already demonstrated, for the hypothesis is identical with the law of elasticity first assumed in Section 1.

Hence, from the reasoning of Section 7, we have for all kinds of elastic systems, the following theorem for ascertaining deflection:

If we express the work of deformation of a body or an elastic system as a function of the exterior forces, including the stresses in the superfluous bars, (if any) as independent exterior forces, the derivative of this expression in relation to any one of these forces, gives the displacement in the direction of the force of its point of application.

When this derivative is plus, the displacement is in the direction of the force; when minus, in the opposite direction.

From the reasoning of Sections 6 and 8, we finally deduce the theorem of least work for any kind of an elastic system:

The elastic forces experienced between the molecules after deformation correspond to a minimum of the work of deformation of the system, expressed as a function of certain stresses, taken with respect to these stresses successively, regarded as independent during the differentiation.

The first step in applying this principle is always the most laborious,

viz.: finding F, the work of deformation of the entire system in terms of certain stresses s_n, $s_{n+1}, \ldots$; the subsequent work consisting simply in placing the partial derivatives of F with respect to s_n, $s_{n+1}, \ldots$, regarded as independent variables for the nonce, equal to zero, thus giving the equations

$$\frac{dF}{ds_n} = 0, \quad \frac{dF}{ds_{n+1}} = 0, \ \ldots,$$

from which the values of s_n, $s_{n+1} \ldots$, can at once be found by elimination, and subsequently the molecular stresses anywhere in the system.

Now it often happens that it is more convenient to express the work of deformation in terms of certain resultants and moments of the molecular stresses, acting along certain interior plane faces, than to express this work in terms of certain elementary molecular stresses as assumed. But we shall find by the aid of the following investigation that the above theorems hold when we substitute the new unknown quantities for those first assumed.

Section 10.—Change of the Unknown Quantities.

Suppose that the work of deformation of an elastic system may be expressed as a function of certain unknown stresses P, Q, $R \ldots$, which, according to the theorem of least work, should be determined by placing the partial derivatives of the work of deformation in relation to these quantities equal to zero.

Now when it happens, as it does very often, that these forces can be expressed as a function of an equal number of other unknown quantities, p, q, $r \ldots$, connected to the first by equations of the first degree, we can express the relationship in the most general manner, as follows:

$$\left.\begin{array}{l} P = a_1 p + b_1 q + c_1 r + \ldots, \\ Q = a_2 p + b_2 q + c_2 r + \ldots, \\ R = a_3 p + b_3 q + c_3 r + \ldots, \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \end{array}\right\}$$

a_1, b_1, c_1, $\ldots$, a_2, b_2, c_2, $\ldots$, a_3, b_3, c_3, $\ldots$, being co-efficients independent of the unknown quantities. We propose now to demonstrate the following very important property:

If we express the work of deformation of the system as a function of the new unknown quantities, p, q, r, $\ldots$, these can be found directly by equating to zero the derivatives of the work of deformation in relation to these same quantities.

In fact, if we call L the work of deformation of the system, we can regard L as a direct function of the unknown stresses P, Q, R, ..., and these as functions of the new unknown quantities p, q, r, ..., from the equations just given.

We have then, by known rules of the differential calculus;

$$\frac{dL}{dp}=\frac{dL}{dp}\frac{dP}{dp}+\frac{dL}{dQ}\frac{dQ}{dp}+\frac{dL}{dR}\frac{dR}{dp}+\ldots;$$

then on substituting here for $\frac{dP}{dp}$, $\frac{dQ}{dp}$, $\frac{dR}{dp}$, ..., their values a_1, a_2, a_3, ..., we obtain the first of the following relations, and the others are similarly found.

$$\frac{dL}{dp}=a_1\frac{dL}{dP}+a_2\frac{dL}{dQ}+a_3\frac{dL}{dR}+\ldots,$$

$$\frac{dL}{dq}=b_1\frac{dL}{dP}+b_2\frac{DL}{DQ}+b_3\frac{DL}{dR}+\ldots,$$

$$\frac{dL}{dr}=c_1\frac{dL}{dP}+c_2\frac{dL}{dQ}+c_3\frac{dL}{dR}+\ldots,$$

.....

But since we have by hypothesis,

$$\frac{dL}{dP}=O,\ \frac{dL}{dQ}=O,\ \frac{dL}{dR}=O\ldots;$$

we deduce as a consequence from the above equations

$$\frac{dL}{dp}=O,\ \frac{dL}{dq}=O,\ \frac{dL}{dr}=O\ldots;$$

which demonstrates the theorem above.

Section 11.

We shall now demonstrate the following theorem: *The differential coefficient of the work of deformation of an elastic system with respect to the moment of a couple composed of two external forces, perpendicular to the straight line which joins their points of application, expresses the rotation of this line about an axis perpendicular to the plane of the couple.*

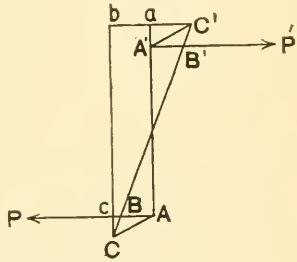


Fig. 5

In Fig. 5, the two equal but opposite parallel external forces P and P^1, both perpendicular to the straight line AA^1 joining their points of application, form a couple whose moment we shall call M. P and P^1 in this case represent "external forces," acting on a structure or forces

replacing the stresses in certain bars, which will be treated exactly as if they were independent external forces in any case.

We have,

$$P.\,\overline{AA^1} = M,\ P^1.\,\overline{AA^1} = M.$$

Now, we can regard the work of deformation of the whole system of necessary bars as a function of the variables P, P^1, which in their turn will be regarded as functions of M, so that the derivative of F in relation to this last quantity will be,

$$\frac{dF}{dM} = \frac{dF}{dP} \cdot \frac{dP}{dM} + \frac{dF}{dP^1} \frac{dP^1}{dM}.$$

But since,

$$\frac{dP}{dM} = \frac{1}{\overline{AA^1}},\ \frac{dP^1}{dM} = \frac{1}{\overline{AA^1}},$$

we have,

$$\frac{dF}{dM} = \frac{1}{\overline{AA^1}} \left(\frac{dF}{dP} + \frac{dF}{dP^1} \right).$$

Now, by section 7, $\frac{dF}{dP}$ and $\frac{dF}{dP^1}$ give the projections of the displacements, along the line of the forces P and P^1 respectively, of the points of application of these forces.

If these displacements are directly along the directions of the forces, as AB and A^1B^1, Fig. 5, then it is evident that, for this case,

$$\frac{dF}{dM} = \frac{\overline{AB} + \overline{A^1B^1}}{\overline{AA^1}}$$

expresses the rotation of the line AA^1 about an axis perpendicular to it and the theorem is proved.

For any case of displacement of the points A and A^1 let C, C^1 be the projections of the new positions of A and A^1 on the plane of the couple. It is evident that the rotation of $\overline{AA^1}$ about an axis perpendicular to the plane of the couple is expressed by the angle between the lines AA^1 and CC^1. Now, if from the point C we draw the straight line Cb parallel to AA^1, and from the point C^1 the line C^1b perpendicular to AA^1 and if we prolong the straight line AA^1 to a, we see that C^1a and ab will be the projections of the displacements A^1C^1, AC upon the direction of the forces, and will have for values $\frac{dF}{dP}$, $\frac{dF}{dP^1}$; both plus (Section 7) when these projections fall upon the side of the forces, both minus when they fall on the side of their prolongations.

The angle C^1Cb has a tangent whose value is

$$\frac{C^1b}{Cb} \text{ or } \frac{C^1b}{AA^1}$$

on neglecting the quantities A^1a, Cc, as infinitely small in relation to AA^1.

As the angle C^1Cb is very small, we can replace it by its tangent, whence

$$\frac{dF}{dM} = \frac{1}{AA^1}\left(\frac{dF}{dP} + \frac{dF}{dP^1}\right) = \frac{C^1a + ab}{AA^1} = \frac{C^1b}{AA^1}$$

which demonstrates the theorem since $\frac{C^1b}{AA^1}$ gives the rotation of AA^1 around an axis perpendicular to the plane of the couple.

As the partial derivatives $\frac{dF}{dP}, \frac{dF}{dP^1}$ are both plus or both minus, according as the projections of the displacements AC, A^1C^1 fall upon the direction of the forces or upon their prolongations, it follows that

$$\frac{dF}{dM} = \frac{1}{AA^1}\left(\frac{dF}{dP} + \frac{dF}{dP^1}\right)$$

will be plus or minus, according as the rotation of the straight line AA^1 is in the direction of the action of the couple or in the contrary direction.

Where P^1 and P represent the resultants of forces as in a beam, uniformly increasing from a neutral axis, as in Fig. 6 (which can be supposed to represent the action of the beam to right of section on part to left), and a plane section AB of the beam before strain, is plane after strain, the same principle holds, and it is to be observed that the rotation of the couple PP^1 is the same as that of the line AB perpendicular to the forces, representing the rotation of the elementary forces two and two, or of the plane section AB after strain.

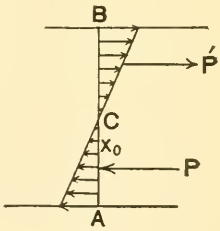


Fig. 6

If this is not evident, call $\alpha =$ the angle of rotation of section AB about C, call p any elementary force below C, a distance x, and let x_0 be the distance of P below C and α_0 the rotation of couple PP^1, formed of the two resultants P and P^1, then by the principle of virtual velocities, since P is the resultant of Σp,

$$P\ (x_0\ \alpha_0) = \Sigma\ (p.x\alpha) = \alpha\ \Sigma\ (p.x)$$

the sum Σ extending from C downward. But since by the principle of moments,

$$Px_0 = \Sigma\,(px)$$

it follows that $\alpha_0 = \alpha$, which was to be proved. Hence in this case, if M represents the moment of the couple PP^1, $\frac{dF}{dM}$ gives the rotation of a plane section AB (Fig. 6) after strain. It must be carefully borne in mind that the forces P and P^1 in question must be treated as independent external forces, for the demonstration of Section 7 shows that $\frac{dF}{dP}$ represents the deflection along P of the apex to which it is applied, only when P is treated as one of the external forces acting on a truss without superfluous members; similarly for P^1.

It is important to note in both the cases examined that if the structure has superfluous members, F can still represent the elastic work of deformation of the entire truss; only, as was shown in Section 7 in taking the partial derivatives, $\frac{dF}{dP}$, $\frac{dF}{dP^1}$, the forces P and P^1 (which generally replace certain stresses) must be regarded as independent of each other and of the stresses in the superfluous bars, which are conceived to be replaced by constant forces having the values of the final stresses in those bars (thus giving a truss without superfluous bars, to which the theory of deflection applies), so that the terms involving these stresses disappear in the differentiation.

Thus to express that the rotation of a certain couple in a structure is α, we find an expression for F the work of deformation of the whole truss in terms of M and certain stresses, T, S ...., in superfluous members. Then although the value of M may depend upon the values of T, S ...., the rule deduced for rotation requires that we differentiate F with respect to the letter M, treating T and S ...., as constants and then state the equality,

$$\frac{dF}{dM} = \alpha.$$

We have been precise in stating the method of dealing with F, the whole work of deformation, for the different cases, as Castigliano has left it in considerable doubt until the applications are reached. The method of virtual velocities, that we have used in demonstrating the principles in question, is so precise as to cause no hesitancy in the applications.

Section 12.—Work of Deformation.

The work of deformation of a tie or strut, is given by equation (3) of Section 1. When the longitudinal stress is uniform at each cross-section but varying with the length of piece, call P the longitudinal stress at any point, normal to the cross-section of area A, and regard it as constant for the distance Δx along the axis of a prismatic bar; then for a gradually applied load the work of deformation for the length Δx is nearly $\frac{P^2 \Delta x}{2EA}$, and for a beam of length l exactly,

$$\frac{1}{2EA}\int_0^l P^2 dx \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Similarly, if S is the shear at any point, then at a distance dx along the axis, we have another equal but opposite shear S which moves, relatively to the first, a distance $\alpha\ dx$, if α is the angle (in arc) through which the part dx of the axis is turned; then calling F the modulus of shearing elasticity, we have the known equation,

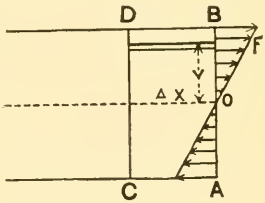


Fig. 7

$$S = \alpha FA$$

if the shear is regarded as uniformly distributed over the cross-section, and if the load is applied gradually, the work of deformation for the length dx is,

$$\frac{S}{2}\alpha dx = \frac{S^2}{2FA}dx;$$

and for the entire length,

$$\frac{1}{2FA}\int_0^l S^2 dx \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Work of Deformation Due to Flexure.

We shall assume the well-known formula for the unit stress f at a distance v from the axis of flexure, when acted on by a couple whose moment about this axis is called M, the corresponding moment of inertia of the section being I,

$$\int = \frac{Mv}{I} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

In Fig. 7, representing a part of a beam, the axis of flexure for the section AB is taken at O and at right angles to the plane of the paper. The axis of Z will be supposed to coincide with the axis of

flexure, so that the moment of inertia of the section AB about the axis of flexure $= \int\int v^2 dvdz$.

Now, if we consider another cross-section CD, Δx from the first, we can conceive the stress f on a fiber of cross-section unity, to be nearly uniform for the very small distance Δx, so that the work of deformation of this fiber contained between the two cross-sections, by equation (3) of Section 1 is for a gradually applied load,

$$\frac{1}{2}\frac{f^2 \Delta x}{E} = \frac{1}{2}\frac{M^2 v^2}{EI^2}\Delta x.$$

If the fiber is regarded as having a cross section $\Delta v \Delta z$, the work of deformation is nearly,

$$\frac{1}{2}\frac{M^2 v^2}{EI^2}\Delta x \Delta v \Delta z$$

Hence the total work of deformation on an elementary slice of the solid Δx long is nearly,

$$\frac{1}{2}\Delta x \int\int \frac{M^2}{EI^2} v^2 dvdz = \Delta x \frac{M^2}{2EI}.$$

We have only to take the limit of the sum of such values for the whole length l of the prism, as Δx diminishes indefinitely, to get the exact expression for the work of deformation due to flexure,

$$\frac{1}{2EI}\int_0^l M^2 dx \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

If the terms A and I are variable, insert to right of integration sign in (1) to (4).

Work of Deformation of an Arched Beam continuously loaded, when its Axis is any Curve whatsoever and the Cross-section is Variable.

Divide the axis of the solid into an even number n of parts, each of the same length l, and so small that they can be regarded without sensible error as straight, and number the sections, beginning at one end, 0, 1, 2. 3, ... n, continuously. Then designate the moments of flexure about horizontal axes passing through the centers of gravity of the sections M_0, M_1, M_2...., M_n respectively; the normal stresses P_0, P_1, P_2.... P_n and the corresponding shearing forces, S_0, S_1, S_2...., S_n, the subscript in each case referring to the section so numbered. The total work of deformation is expressed by the formula,

$$\frac{1}{2E}\int\frac{M^2}{I}\,ds+\frac{1}{2E}\int\frac{P^2}{A}\,ds+\frac{1}{2F}\int\frac{S^2}{A}\,ds,$$

the integrations covering the whole length of the solid.

Now, if we describe a curve, taking for abscissas the values of the arc s (the origin being taken at one end) and for ordinates the corresponding values of $\frac{M^2}{I}$, it is clear that the area between this curve, the axis of abscissas and the extreme ordinates will be represented by the integral, $\int\frac{M^2}{I}\,ds.$

But according to Simpson's formula we can express approximately this area in the following manner: we divide the portion of the axis of abscissas comprised between the extreme ordinates into an even number n of parts, each of length l, designate the ordinates at the successive points of division, y_o, y_1, y_2, ... y_n, then the area sought is equal to,

$$\frac{l}{3}(y_o+4y_1+2y_2+4y_3+\ldots\ldots+4y_{n-1}+y_n,)$$

Therefore we have,

$$\int\frac{M^2}{I}\,ds=\frac{l}{3}\left(\frac{M_o^2}{I_o}+4\,\frac{M_1^2}{I_1}+2\,\frac{M_2^2}{I_2}+4\,\frac{M_3^2}{I_3}+\ldots\ldots+4\,\frac{M^2_{n-1}}{I_{n-1}}+\frac{M_n^2}{I_n}\right)$$

Applying the same reasoning to the other terms, we have the work of deformation of the entire solid equal to,

$$\left.\begin{aligned}&\frac{1}{2E}\frac{l}{3}\left(\frac{M_o^2}{I_o}+4\,\frac{M_1^2}{I_1}+2\,\frac{M_2^2}{I_2}+4\,\frac{M_3^2}{I_3}+\ldots\ldots+4\,\frac{M^2_{n-1}}{I_{n-1}}+\frac{M^2_n}{I_n}\right)\\&+\frac{1}{2E}\frac{l}{3}\left(\frac{P_o^2}{A_o}+4\,\frac{P_1^2}{A_1}+2\,\frac{P_2^2}{A_2}+4\,\frac{P_3^2}{A_3}+\ldots\ldots+4\,\frac{P^2_{n-1}}{A_{n+1}}+\frac{P_n^2}{A_n}\right)\\&+\frac{1}{2F}\frac{l}{3}\left(\frac{S_o^2}{A}+4\,\frac{S_1^2}{A_1}+2\,\frac{S_2^2}{A_2}+4\,\frac{S_3^2}{A_3}+\ldots\ldots+4\,\frac{S^2_{n-1}}{A_{n-1}}+\frac{S_n^2}{A_n}\right)\end{aligned}\right\}\ldots\ldots\ldots\ldots(5)$$

If the quantities M, P, S, I, A are not continuous functions of the arc s (in which case alone Simpson's formula is applicable) we must divide the solid into such portions as are continuous, taking as points of

division those where the changes are sudden, and afterward apply (5) to each of these parts and add the results.

The above formula is equally true for a straight beam, and it is interesting to note in the last case that when the section of the solid is regarded as constant, the formula is exact, as can easily be proved. As it stands, the formula is practically exact, and affords a means of investigating the strength and stability of the arch of variable cross-section, which ordinary analytical methods leave untouched.

For special cases of straight beams, the formula can be modified slightly with advantage, but we shall not stop to consider further the applications to straight beams, as ordinary methods suffice; but it may be remarked that the method of work leads to the well known formulas for the strength and deflections of beams, and some of the solutions are quite direct and elegant.

Section 13.—Solid Arch Fixed at the Ends.

The problem is to find the resultant pressure at the crown in position, direction and magnitude, having given the dimensions of the arch and the loading.

The resultant on any normal section of the arch is generally inclined to the normal to the section, and may not pass through the center of gravity of the section. It can therefore be decomposed into a normal pressure P and shearing force S. Now if we conceive two opposed forces each equal and parallel to P to act at the center of gravity of the cross-section, we do not disturb equilibrium; but we have the one force P giving a uniform compression $\frac{P}{\omega}$ over the cross-section, calling ω its area, and the other combined with the original component P acting at a distance d from the center of gravity, giving a couple whose moment is $M = Pd$, which causes a stress uniformly increasing from the center of gravity, tension on one side, compression on the other, whose amount is $\frac{Mv^1}{I}$, where v^1 is the distance of the fiber experiencing this stress from the neutral axis and I, the moment of inertia of the cross-section about a horizontal axis passing through its center of gravity. The maximum fiber stress is experienced at the intrados or extrados, so that if v represents the distance from the center of gravity of the cross-section to either curve, we have the maximum unit fiber stress given by the formula,

$$\frac{P}{\omega} \pm \frac{Mv}{I}$$

Similarly at the crown joint, we can decompose the single resultant there into a normal thrust (p) acting at the center of gravity of the joint, a shear (s) acting along the section, and a couple (p,p) whose moment is $m = pd$.

Then by the method of the derivative of work, if we suppose one-half of the arch removed and its action at the crown to be replaced by the forces p and s, which, regarded as external forces, will hold the other half in equilibrium; the derivative of the elastic work of deformation of the half arch with respect to either of these forces will give the corresponding displacement of the crown in the direction of the force (Section 9), and by Section 11, the derivative with respect to the moment m, gives the rotation of the plane section where it is applied.

Thus if L' and L'' represent respectively the work of deformation of the left and right halves of the solid arch considered, $\frac{dL'}{pp}$ gives the horizontal displacement of the point of application of p at the crown of the left half and $\frac{dL''}{dp}$ for the right half; so that $\frac{dL'}{dp} + \frac{dL''}{dp} = \frac{dL}{dp} = O$, where $L = L' + L''$; for these displacements are necessarily equal but of opposite signs, since p is directed to the left in one case and to the right in the other. Similarly the vertical displacements are equal and of contrary sign, so that,

$$\frac{dL'}{ds} + \frac{dL''}{ds} = \frac{dL}{ds} = O.$$

Lastly, the rotation of the section of the crown for the semi-arch to the left must be equal and of contrary sign to the rotation of the same section for the semi-arch to the right, so that,

$$\frac{dL'}{dm} + \frac{dL''}{dm} = \frac{dL}{dm} = O.$$

The same results can be deduced by the principle of least work of Section 9. Thus it is easily shown that the complete stress between any two molecules can be expressed as a linear function of p, s and m; therefore we can deduce the values of p, s and m, and hence of L, in terms of the stresses t_1, t_2, t_3, at any three points, which may be regarded as the three unknown stresses to be found by placing (Section 9),

$$\frac{dL}{dt_1}=O, \frac{dL}{dt_2}=O, \frac{dL}{dt_3}=O;$$

whence by Section 10, since t_1, t_2, t_3, can be expressed as linear functions of p, s, m, we can find the latter at once by placing,

$$\frac{dL}{dp}=O, \frac{dL}{ds}=O, \frac{dL}{dm}=O,$$

as found by the method of deflections.

The tedious part of this solution is in finding L. To do this, we proceed, as in Section 12, for the arch of variable cross-section, to divide the line passing through the centers of gravity of all the cross-sections of the arch ring into an even number n of equal parts, of length l, and denoting the normal pressure, shear and moment at any cross-section by the letters p, s and m with the subscript pertaining to that cross-section, we have the total work of deformation given by formula (5) of Section 12, in which, however, the terms pertaining to s can be omitted, as producing no sensible influence upon the result. In fact for a first approximation, the terms involving p, giving the influence of the uniform compression, can be omitted.

It is evident that the values of $m_1\, p_1\, s_1$, $m_2\, p_2\, s_2 \ldots$, for any section, can be expressed as linear functions of m, p and s for any kind of loading, so that L will eventually involve only terms of the first and second degrees as to m, p and s; and when we differentiate L successively with respect to m, p and s, and place the results equal to zero, we have three equations of the first degree with respect to m, p and s, from which they can be found by elimination, and ultimately m_1, p_1, $s_1, \ldots$, and the maximum fibre stresses at any of the cross-sections by a formula already given. Also, since at any cross-section as 2, $m_2 = p_2\, d_2$, we have the distance of the center of pressure on that joint from its center of gravity given by the formula $d_2 = \frac{m_2}{p_2}$ from which the line of pressures can be drawn; or if preferred, p and s can be combined at the crown, at the distance $d = \frac{m}{p}$ from the center of gravity of the crown joint, thus giving the desired resultant pressure at the crown, from which the line of pressures can be located by the usual graphical construction.

Stresses Due to Temperature.

If the arch fits without strain to the span and abutments at the temperature t, then at the temperature t^1, if free, it would have a similar

shape to its first figure, so that the angles of the extreme sections would be exactly the same in the two cases; but the distance between the centers of these sections, originally l, would be increased by $\alpha l\,(t^1 - t)$ where α is the increase of length of the material of the arch for a length unity, and a rise of 1 degree of temperature. Now, since the span and skew-backs are invariable, the crown joint of the left half of the arch, if free to expand by itself, would move to the right, and that of the right half if free, to the left—distances whose sum $= \alpha l\,(t^1 - t)$. But the new thrust at the crown would move this joint to the left, if acting only on the left half of the expanded half arch, a distance $\frac{dL^1}{dp}$, and the crown joint of the right half, if free, to the right, a distance $\frac{dL''}{dp}$, so that the total

$$\frac{dL^1}{dp} + \frac{dL''}{dp} = \frac{dL}{dp},$$

must exactly equal $\alpha l\,(t^1 - t)$, in order that the crown joints of the two halves may exactly coincide after deformation. We have, therefore,

$$\frac{dL}{dp} = \alpha l\,(t^1 - t),$$

a condition which may be derived by putting the derivative with respect to p equal to zero of the expression,

$$L - \alpha l\,(t^1 - t)\,p = O.$$

From the reasoning above, the vertical displacements of the crown joints for the two halves, as well as the rotations, must be equal and of opposite signs, so that we deduce as before,

$$\frac{dL}{ds} = O, \quad \frac{dL}{dm} = O,$$

in addition to the previous equation, from which equations the three unknown quantities, p, s and m can be found as before. If it is desired to find the stresses due to temperature alone, then the terms in L pertaining to the loading should be omitted.

Solid Arch Hinged at Ends.

In this arch the position of the horizontal thrust p at the abutments is known, and by working from an abutment we can easily express $m_1, p_1, s_1, m_2, p_2, s_2, \ldots$, in terms of p alone, and thus find L from formula (10) of Section 12. For span invariable, to determine p, we put $\frac{dL}{dp} = O$, and for a rise of temperature, $(t^1 - t)^o$, we have

$$\frac{dL}{dp} = dl\,(t^1 - t).$$

The last formula is evident, since if one end of the arch was free to slide horizontally the distance $\alpha l\,(t' - t)$ from the rise of temperature, the thrust p acting there would have to force it back a distance $\frac{dL}{dp}$ in the direction of the force, to cause the end to assume again its original position.

If one end of the arch is on rollers and a tie bar of length l, section ω and modulus e connects the ends, its increase under the horizontal thrust p, which equals the tension in it, is $\frac{lp}{e\omega}$. Here the end is moved in the opposite direction to the pull of the tie bar, so that if L is the work of the arch,

$$-\frac{dL}{dp} = \frac{lp}{e\omega} \therefore \frac{dL}{dp} + \frac{lp}{e\omega} = O.$$

from which p can be found.

There are no stresses due to temperature in this arch if the tie and arch are of the same material.

To get the vertical deflection of the crown under any loading, conceive a small force q to act vertically downward there, and find L the total work of deformation as before for any of the cases examined; then $\frac{dL}{dq}$ = vertical deflection at crown, no matter how small q is, and hence when $q = O$, for which the deflection is that due to the original loading.

Section 14.—Composite Structures.

Space forbids giving any extended numerical illustrations of the theory of least work; besides it is unnecessary, as Castigliano has devoted in his "Systemes Elastiques," 165 pages to the applications, which there should be no difficulty in following after what has preceded. Some of the numerical results, however, are interesting by way of comparison with approximate methods.

Thus in the trussed beam, Fig. 8, where the beam is of wood 8 meters long, $\overset{m}{0.2} + \overset{m}{0.2}$ cross-section, and the ties of iron .024 meter in diameter, the load is taken at 180 kilograms per meter of length, and it is supposed that the truss is put together without stress at 15 degrees C. (59 degrees Fahr.).

The work of the two short wooden struts is neglected, because it is very small on account of their large section. The work of the longitudinal stress in the ties and beam is easily expressed by (3) of Section I, in terms of T, the tension in the inclined ties, putting the co-efficient of elasticity of iron as twelve times that of the wood. The work due to flexure of any one of the three segments of the horizontal beam can be computed by the formula $\frac{1}{2EI}\int M^2 dx$, by expressing M as a function of the distance x from one end of the segment (thus for end segment $M = -Rx + Tx \sin. \beta + \frac{1}{2} px^2$); or we can use, from (5) of Section 12, the formula,

$$\frac{1}{2EI}\frac{l}{3}(M_0^2 + 4M_1^2 + M_2^2),$$

where M_0 is the moment at one end, M_2 at the other and M_1 at the middle of the segment considered, or preferably a shorter formula that may be derived from this.

The sum of the elastic work of the ties and beam will now be found to be expressed in terms of T^2 and T, whence by Section 9 we find the true value of the tension T in the inclined ties, by placing the derivative of this sum in relation to T equal to zero, giving $T = 2\,120$ kilograms, from which the other stresses can at once be found.

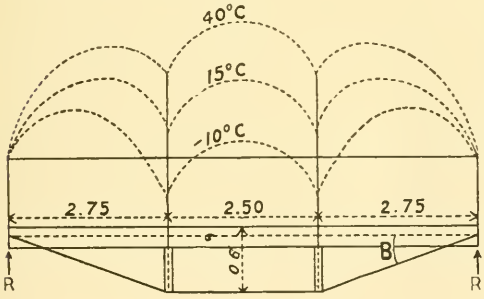


Fig. 8

To find the stresses at another temperature, by Section 6, we must add the term $-2\lambda T$ to the work already found, representing by λ the amount by which each inclined tie is too short when the horizontal tie is placed in position at the new temperature, and again place the derivative of the sum with respect to T equal to zero.

In this way we find at the temperature 40 degrees C. (104 degrees Fahr.), T = 1 380 kilograms, and at — 10 degrees C. (14 degrees Fahr.), $T = 2\,410$ kilograms. The bending moments are represented by the ordinates to the dotted curves shown in the figure, the maxima for 15 degrees C. and 40 degrees C. occurring at the center of the beam,

where the greatest compressive stress due to flexure and the uniform longitudinal compression combined, is found to be 20 kilograms per square centimeter at 15 degrees C., and 32 kilograms at 40 degrees C. The maximum stress at — 10 degrees C. occurs at 1.15 meters from the end and is 15 kilograms per square centimeter.

As it will be instructive to compare these exact results with approximate ones computed on the supposition of hinged joints, and that the beam does not aid by flexure except in carrying the load on any segment of it to the ends of that segment, I have computed for the end reaction 472 kilograms, $T = 2\,215$ kilograms, and the uniform compression along the beam = 2 163 kilograms. Now, regarding the end-segment of the beam as a supported beam, 2.75 meters long and loaded with 180 kilograms per meter of length, we have the maximum compression in the top fiber = 127 630 kilograms per square meter, which, added to the uniform compressive unit stress $2\,163 \div .04 = 54\,075$, gives a total maximum of 18.1705 kilograms per square centimeter. Similarly, the total maximum for the middle segment, regarded as "fixed at the ends," is 12.4385 kilograms per square centimeter—values below the 20 kilograms per square centimeter found above for 15 degrees C., and far below the 32 kilograms found for the 40 degrees C. We see from this comparison that whilst the values of T do not vary greatly for changes in temperature, yet the fiber stress in the beam experiences very wide changes for this combination of wood and iron, and that an approximate computation, as above, would not be on the side of safety, at least for the cross-sections given.

Curved Roof Truss with Tie Rods. Plate XXV.

In the elegant design shown in the plate, of a curved iron truss with tie rods, it will be found for assumed dimensions given in meters,* that for a symmetrical load of 760 kilograms per meter in length of roof, from Sections 0 to 2, and 864 kilograms from Sections 2 to 4, that the stresses in the ties marked T_1 and T_4 are respectively $T_1 = 16\,690$ and $T_4 = 2\,090$ kilograms. To find these values the elastic work of half the truss was found in terms of T_1 and T_4, and then the partial derivatives of this work

* The arched member has a total depth of 0.6 meter, and its flanges are each formed of similar irons, whose combined area = .003898 square meter, and moment of inertia, about a horizontal axis midway between the flanges, = .000315.

with respect to T_1 and T_4 put equal to zero. The two equations resulting give the above values of T_1 and T_4.

The usual statical computation on the supposition of hinged joints gives $T_1 = 18\,000$ and $T_4 = 1\,340$ nearly. There is a wide variation in the bending moments for cross-sections 0, 1, 2, 3, 4, as shown in the following table.

0	1	2	3	4
—318 —180	+110 +2223	—3489 0	—1313 +164	+1122 0

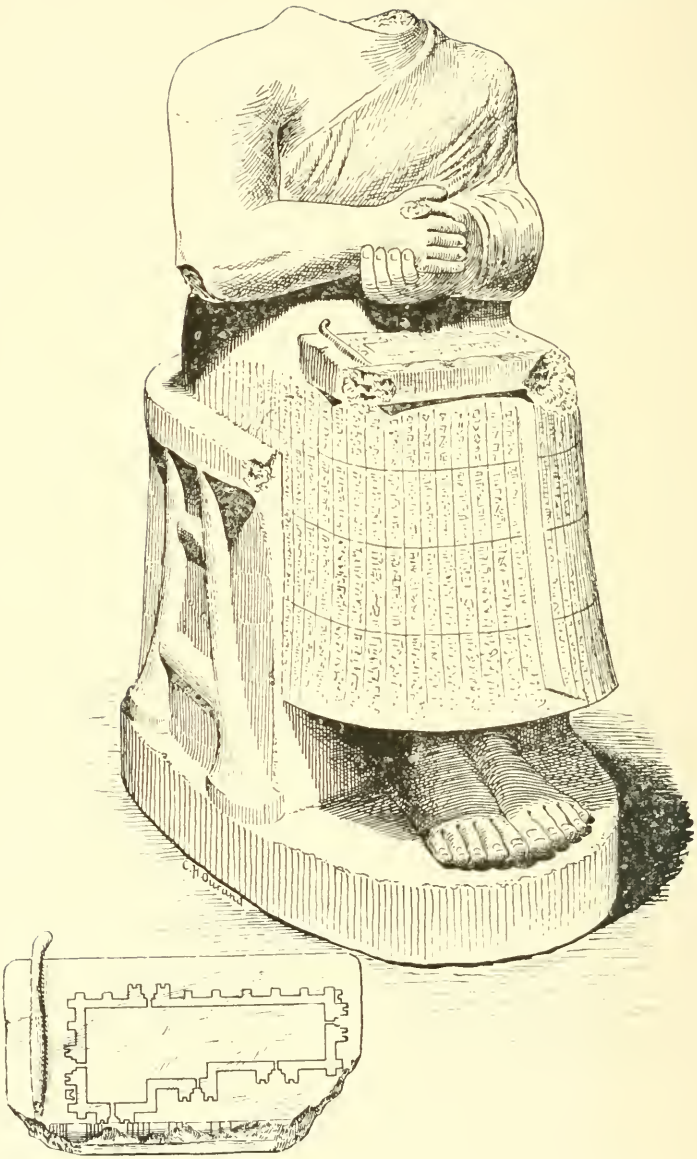
The upper figures refer to the exact, and the lower to the approximate, method of computation. The greatest fiber stress, including the longitudinal compression, is by the exact method, 807 at Section 2, and by the approximate, 770 kilograms per square centimeter at Section 1; so that the arch of uniform section would be safe if designed by the approximate method. Is it not best in practice, however, to actually make the joints at 0, 2 and 4 hinged, so that the sections can be designed by the ordinary laws of statics to carry any given stress? We can thus fit the sections exactly to the stresses and the influence of misfits does not come in to disturb the computations.

It would take us too far to enter further into the applications of the method of least work. It may be said in brief, as to the method to follow for any elastic system, whether eccentrically loaded or not, that the work of the members can generally be expressed in terms of the unknown stresses in certain bars; and that the partial derivatives with respect to these stresses, put equal to zero, furnish always as many equations as unknown stresses, so that the latter can readily be found by elimination.

It may be interesting to know that if the arched member above is replaced by a straight beam, as in the ordinary form of roof truss, that the greatest fiber stresses, as computed by the exact and approximate methods, do not differ much. Castigliano has also worked out the stresses in a crescent roof-truss with triangular bracing, connected to the arch member by pins passing through the centers of gravity of the cross-sections. The centers of pressure at these sections were frequently found

to lie as much as one-fourth the depth of the arch from the center, so that the fiber stresses were much larger than statics alone would give on the supposition of hinged joints; from which it may reasonably be inferred that the unit stresses in the continuous upper chords of our ordinary trusses are in excess of those given by usual methods, and simply because the hypothesis of joints perfectly free to move is never realized. It seems useless then to enter into any great refinement in our ordinary statical computations.

PLATE XXV.
TRANS. AM. SOC. CIV. ENG'RS
VOL. XXIV. Nº 471.
CAIN ON
ELASTIC SYSTEMS.



AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

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472.

(Vol. XXIV.—May, 1891.)

THE BEGINNINGS OF ENGINEERING.*

By J. ELFRETH WATKINS, Assoc. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION AT CRESSON, JUNE 28TH, 1890.

WITH DISCUSSION.

"Many a patient investigator has puzzled his brain in trying to solve the problem which had yielded to a more fortunate laborer in the field, centuries before." Sir John Hawkshaw's Presidential address before the British Association for the Advancement of Science, in 1875.

"It is not in our power to appropriate to ourselves the experiences and results which the future alone can bring. But in a common sense, we are enabled to prolong our life backward into the past by appropriating the experiences of those who were before us, and by becoming acquainted with their views as thoroughly as if we had been their contemporaries. The means of doing this is also an elixir of life."—*Hermann Kopp.*

From an examination of the *Transactions* and *Proceedings* of the American Society of Civil Engineers, I find that it has not been customary to present historical papers at conventions, save in the annual presidential address, or in the memoirs of the pioneer members of the Society, two or three of whom have placed their reminiscences on

* I am indebted to Dr. Cyrus Adler, Assistant Curator, Department of Oriental Antiquities in the U. S. National Museum, for valuable assistance in preparing the chapters upon the methods of ancient engineering. To James B. Francis, M. Am. Soc. C. E., and H. W. Clarke, M. Am. Soc. C. E., for information in regard to early American engineers and surveyors; and to W. A. De Caindry, Chief Clerk, Commissary General's Office, U. S. A., for references to literature relating to the engineers in the Continental Army, and those connected with the establishment of the West Point Military Academy; also, to Ashton S. H. White, Librarian of the 33d degree Masonic Library of the Supreme Council for the Southern Jurisdiction, U. S. A., at Washington, who kindly directed my researches through the valuable volumes under his care.

record. But I have overcome any scruples that might have deterred me from presenting this paper, from the fact that, while it is the province of many of the members of this Society to direct the progress of engineering science in the future, it is my function, in the institution with which I am connected, to assist in preserving the history of the achievements of the past. I feel, therefore, that I need make no apology for asking your attention to a subject which has for me, at least, the most fascinating interest.

The most remarkable trend of modern thought, notwithstanding the effervescent boastfulness of the nineteenth century, is an appreciation of the work done by those who have gone before. During this busy age of specialties in every profession, the active thinking men that can spare the time from bread-winning are engaged more or less in looking backward. Retrospection is as surely the watchword of the modern philosopher, as was introspection of his mediæval brother. In the world of applied science, no less than in the domain of ideas, we must reverse our mental telescopes, if we would measure at its full the glory of human achievement. To aid us in our investigations the excavator, the archæologist, the ethnologist and the philologer are constantly at work. In our longings to complete the history of the development of any art, we must look to them to supply the missing links in the chain of human activity that connects us with the past.

In tracing the history of the beginnings of engineering it has seemed necessary to review some parts of the record of early human achievement, which the critical student might deem irrelevant, since the early builders were guided by the knowledge of the results of experiences handed down from generation to generation, rather than from physical laws scientifically considered. I take it, however, that those who used the lever, the roller, and the inclined plane to the best advantage; who, knowing that water seeks its level everywhere, constructed dam and dyke for water supply; who built embankments of the most economical and lasting form; who quarried and hewed to the line, were gathering and garnering the facts with which in the later centuries the foundation of the science of engineering has been laid.

The science of engineering did not have its origin at any stage in the world's history. While no one race or era can lay claim to its inception or its birth, every civilization may be said to have aided in its development. If astronomy had its origin with the Chaldean shepherds, who

with the naked eye made the observations which governed them in performing the duties of their yearly round of husbandry, bridge engineering may be said to have had its beginning when the first tree was felled across the brook too deep to ford. If architecture began when the first flat unhammered stone lintel was laid across the upright boulders that constituted the sides of the prehistoric dolmen, hydraulic engineering had its inception when the same aboriginal deepened the bed of the rivulet with his naked hand or wooden paddle, that he might increase the water supply for his flocks and herds.

If sculpture began when the pre-historic unspeaking cave-dwelier dug out rude figures on the clay walls of his home, steam engineering was in its infancy when the Egyptian monarch amused his friends with his revolving toy—the ælopile—which Hero describes. If music began when the savage chanted his weird song to the time of the gourd-rattle, then electrical engineering was in its swaddling clothes centuries ago, when the Chinese coaster steered his junk by a sea shell filled with oil, upon which floated the bit of reed, enclosing a magnetic needle, pointing always to the southern cross.

A knowledge of the same physical law that led the Assyrian engineer to place inflated goat skins under the raft upon which he floated the huge monolith for the palace of his king, has led the modern naval architect to increase the safety of the Trans-Atlantic steamship by making air-tight compartments of her hold.

The relations between engineering and architecture have been frequently discussed by able writers, without the establishment of any definite dividing line between the two professions, or as some have held, branches of the same profession. Ferguson, the modern historian of architecture, asserts that: "Where the engineer leaves off, the art of the architect begins. His object is to arrange the materials of the engineer, not so much with regard to economical as artistic effects, and by light and shade and outline, to produce a form, that in itself shall be permanent and beautiful." When competent writers find difficulty in defining the boundary between two professions which have been separated only in modern times, it will not be necessary for me to offer any excuse for considering the works of the ancient engineer-architects as a whole.

As astrology and astronomy bore the closest relationship to each other in the remote past, so architecture may be said to have been the handmaid of engineering in the beginning. The superstitious belief

that caused the Babylonians to erect an observatory in every prominent city, from which the fate of the nation, indicated by the position of the planets, was reported regularly to the king, resulted ultimately in the foundation of the science of astronomy.

So, again, the religious element in man's nature—which led the Incas of Peru to erect temples for the worship of their deities; and the Egyptians to quarry and transport for weary miles the 300-ton monolith at Karnak, and the huge stones for the pyramids which mark the tombs of the Pharoahs—was the incentive that inspired the first steps in the progression of that art which has made it possible in our day to tunnel the Saint Gothard, and to transport Cleopatra's needle from the ancient city of Alexandria across the stormy Atlantic to the metropolis of the new world, the anniversary of the discovery of which a short four hundred years ago, we shall soon be called upon to celebrate.

Investigation and discovery continue to confirm the belief of the evolutionists, that the period of man's existence on this planet is to be measured, not by centuries, but by tens of thousands of years. Modern explorers have reached the conclusion that the great temple of Karnak and other ancient buildings of the Thebiad, were constructed to a great extent from the remains of other structures, which were as ancient when they were dismantled, as are these edifices which the archæologists of the nineteenth century are exploring with such zeal and acumen. The temples at Pæstum, in Calabria, Italy, which were described by Livy as belonging to the Cyclopean or pre-historic age, when Augustus Cæsar visited them as a tourist during the lifetime of Christ, remain to-day in substantially the same condition as when that monarch explored them nineteen centuries ago.

A close observing American engineer who examined these temples carefully forty years ago, as well as many other classic remains in Italy and Greece and Sicily, has formulated the striking theory that uncared-for ruins will remain reasonably intact for a length of time based upon the cube or higher power of the average volume of the stone blocks of which the walls are built. Thus, if it is found that a wall which is composed of stones averaging $2\frac{1}{2}$ cubic feet exists one hundred years without repair, another in which the stones average 10 cubic feet will last not merely four times, but at least sixty-four times as long, or for six thousand years or more.

Be that as it may, any attempt to assign a date to many of the ruins

in Egypt, Greece, Rome and Peru, of which no record exists, must, of necessity, be the merest conjecture. Hence engineering architecture must be regarded as a pre-historic art.

As excavation and exploration demonstrate, beyond peradventure, that the ancients accomplished feats of engineering which must excite our profound admiration even in this day of the triumph of the mental over the material world, the belief grows upon me that it is not impossible that other agencies besides brawn and muscle were called into the service of these peoples of antiquity, and I am reminded of the belief of Helvetius, that modern progress may have resulted from a rediscovery of the arts lost in the abyss of the ages which separate us from the *Sæculo Sapienti.*

In discussing the development of ancient engineering, there is a double limitation. First, we are constrained to pay attention only to those races who have directly influenced our civilization; and again, we are confined to those nations, the histories of which, by ancient authors, can be fully confirmed by the monuments of writing or of art that have been definitely interpreted by trustworthy modern scholars.

The Babylonian and Assyrian inscriptions, which were deciphered previous to the middle of our century, were mainly devoted to the record of the deeds of valor of the warrior kings and their followers in the struggle with other warlike tribes; and the remains of their public works formed the chief basis of our knowledge of the engineering skill developed by these nations. More recent discoveries and research, thanks to archæological activity, have resulted in the deciphering of inscriptions which throw additional light upon their engineering methods; so that now it is the lament of the archæologist, interested in other fields, that from these monuments more is to be learned in regard to the construction of public works, than of the general history of these ancient races.

Of the races of antiquity to be considered (and the list is by no means exhaustive), I will mention, in what seems to me to be their order of importance, Chaldea, Babylon, Egypt, Assyria, Phœnicia, Etruria, Palestine, Moab, Persia, India, China, the Incas. To this aggregate every form of engineering was known, which did not require the application of the generated forces. They built canals for transport and irrigation, reservoirs and aqueducts, docks, harbors and light-houses. They erected bridges of wood and stone, as well as suspension bridges; laid out roads, cut tunnels, constructed viaducts, planned roofs for their massive build-

ings; tested the strength and discovered the weakness of their building materials; instituted elaborate systems of drainage; planned fortifications; designed engines of attack and floating bridges, devised methods for the transport of heavy objects—in fact covered to a greater or less degree all departments of hydraulic, bridge and road, sanitary, military and mechanical engineering. Time will not permit me on this occasion to enter into an elaborate discussion of the practices of ancient engineers, save to allude to the more important monuments of their skill which have withstood the ravages of many centuries.

From the beginning, the progress of engineering development in every nation has been largely influenced by its political history. Rulers of small states and principalities had little incentive to construct public works. But as power became centralized and territory was added, their wealth was increased; the perpetuity of the civil power in the state then depended largely upon the extension of its internal improvements and the development of its resources. If the rulers administered power with wisdom, a gradual advance in civilization took place, and wherever these centers of advanced civilization were located there we find engineering works of importance. These facts were true of ancient as well as of modern nations, as the histories of Egypt, Assyria, Babylonia and Rome on the one hand, and Greece and other small states on the other, fully demonstrate.

The engineer-architect held a position of power and influence in all ancient communities. He was the adviser of the king, his ministers and his generals, and usually held a sacred office in addition to his secular duties. His burial was solemnized with pomp and display, and statues and other monuments were erected to perpetuate his memory. M. de Sarzec found a statue* at Tello (see frontispiece), from the earliest period of Chaldean art (about 4000 B. C.), which holds upon its knees a tablet "on which the plan of a fortress, with its bastions and posterns is engraved in outline, just as an architect of the present day would draw it. A graduated rule, that is to say, one subdivided into fractions of unequal but proportional length, $10\frac{3}{4}$ inches long, is carved in relief beside the plan, for which it serves as a scale; finally, at the side lies the style with which the architect engraved his design."†

In Egypt, 3700 B. C., there existed an officer—the "Superintendent of Works, who had charge of the construction and repairs of public

* Now in the Louvre.
† Manual of Oriental Antiquities, Ernest Babelon, page 29.

edifices and roads."* The authority for this fact is established by a wooden statute in the Bulak Museum, discovered at Sakkarah by Marietta Bey. It represents an official who bore the title of Superintendent of Works under the 4th Dynasty. †

Lepsius‡ describes an inscription left upon the rock in an ancient quarry in Egypt by a royal high architect, in the dynasty of the Psammetici, giving the pedigree of his family for twenty-three generations, each of whom held the same office in succession, in addition to performing his duty as priest.

Ancient Greece, during the memory of man, was almost constantly a divided territory of small states, over which no one monarch governed long. As there was neither centralization of wealth nor power, it is not surprising that few national engineering works of importance were projected. Greece being a mountainous country with numerous rapid streams, and penetrated everywhere by arms of the surrounding sea, no incentive existed to construct canals for irrigation as in Egypt, or aqueducts as in Rome.

The Etruscans, the immediate predecessors of the Romans, performed many feats of engineering. Their subterranean tombs demonstrate that they were skilled in tunneling, excavations and masonry. Dennis§ states that "they drained lakes by cutting tunnels through the heart of mountains, and diverted the courses of rivers to reclaim low and marshy ground, just as the Val di Chiana has been rescued in our own time." Some of these works are not only still extant but efficient, although they were constructed several centuries before the foundation of Rome (753 B. C.).

It was one of the boasts of the Emperor Augustus that he found Rome a city of brick, and left it a city of marble. It is from works constructed during the Augustan age, that we can form a true estimate of the engineering skill of the Romans, although it is worthy of note that some of the best Roman works were constructed by Greek engineers. The greater works were carried out by soldiers, prisoners, or paid laborers; the materials, stone, etc., were either quarried by slaves or military prisoners, taxed from the land owners, or purchased and paid for. The engineers of ancient Rome were especially noted for their

* Egypt under the Pharoahs. Brugsch, Vol. I, page 6.

† Egyptian Archæology. Maspero, page 212.

‡ Discoveries in Egypt, Ethiopia, etc., 2d ed., page 318.

§ Cities and Cemeteries of Etruria.

ability to construct durable roads and aqueducts, and the handsome public and private baths, which were built in every Roman city; their amphitheatres, temples and palaces exemplify the type of work in which the engineer was employed during the era of wealth and luxury, when Rome was mistress of the world.

Even during the years of war and conquest the civil engineer was never idle, in fact the power of the Roman Empire was upheld as much by the knowledge, genius and energy of its engineers, as by its generals.

In Chaldea, the soil, when moistened and dried in the sun, was peculiarly fitted for the uses of the builder. The bricks found in the vaults at Ur, where we are told that Abraham once lived, are from 12 to 16 inches square, and 3 to 4 inches thick. The Tower of Babel which is described in Genesis* (ii, 3, 4) was built of bricks.

Egyptian bricks were usually very large; in ruins at Memphis, they measure 15 inches in length, 7 wide, and $4\frac{3}{4}$ thick. From the commencement of the Theban epoch, the stamp of the royal oval is often found upon them (see Fig. 1).†

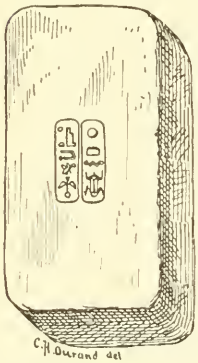


Fig. 1.

Diodorus tells us that the vaults of the Ninevite palaces were covered with layers of lead and bitumen to resist the water from the summer rains, and numerous inscriptions confirmed this statement. Bitumen was used in the construction of Noah's Ark, according to the Biblical and cuneiform accounts. It was also used to make water-tight the box of bulrushes in which the infant Moses was committed to the Nile.

The larger works of the Babylonians were also composed mainly of bricks, the interior of the walls being sun-dried, the exterior layers being small and kiln-burned. In the ruins of Khorsabad are found walls of sun-dried bricks faced with stone (see Fig. 2). These walls were noted for their size more than for engineering skill in construction. Some of

* "And they said one to another, go to, let us make brick, and burn them throughly. And they had brick for stone, and slime had they for mortar."

The slime alluded to here was bitumen—a petroleum earth similar to that now found in the neighborhood of the Dead Sea.

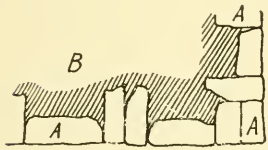
"And they said, go to, let us build us a city, and a tower, whose top may reach unto heaven; and let us make us a name, lest we be scattered abroad upon the face of the whole earth."

† Prisse, Histoire de l'Art Egyptien, page 179.

these bricks have lasted so well that the ruins of Mesopotamia have furnished materials for many edifices in modern Persia; and the stamp of Nebuchadnezzar is not uncommon in the walls of brick buildings constructed during the last two centuries and inhabited at this day. One of these bricks 16 inches square and 4 inches thick is shown in Fig. 3. The translation of the inscription reads: "Nebuchadnezzar, King of Babylon, Restorer of the Pyramid, and the tower, eldest son of Nabopolassar, King of Babylon I."

Ancient Hydraulic Engineering, etc.

From the beginning, the mind of man was turned toward devising means to satisfy his necessities. He must have water to quench his thirst, and that of his tribe and their flocks and herds, or to irrigate his land; and, as may have been expected, the cradle of hydraulic engineering was to be found on the shores of the Euphrates, the Tigris



Assyrian Masonry (Khorsabad)
A.A.-Stone.
B-Brick backing.

Fig. 2.

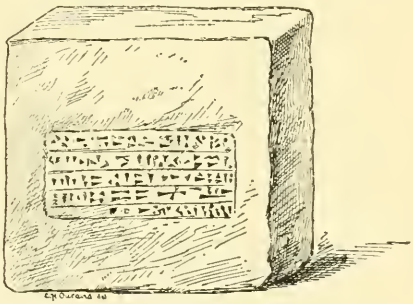


Fig. 3.

and the Nile, where also was located the earliest advanced civilizations. Five thousand years of wind and sun have not succeeded in obliterating the remains of the chain of canals and storage lakes constructed by successive Egyptian monarchs, by which the once barren and unproductive valley of the Nile became fertile and prosperous.

What is probably the oldest alphabetic inscription* in the world, since it dates to the 10th century B. C., is the Moabite Stone. Near the conclusion of the inscription it is recorded that "Mesha built two conduits, and since there were no cisterns in the city, Karcha, Moab, he ordered the inhabitants of the city to place a cistern in each house. He then

*Discovered on 19th August, 1868, and now preserved in the Louvre, Paris, and contains an account of the successful rebellion of Mesha, King of Moab, against Israel.

The fact is also recorded that among other building operations he rebuilt one city and laid out streets in another.

had a conduit constructed" by the Israelitish prisoners to supply water to these cisterns.

At Negoub* a tunnel through the rock opens by two low-arched outlets upon the river. It is of considerable length, and is continued for about a mile by a deep channel, also cut in the rock, but open at the top. An inscription in the tunnel was translated by Dr. Hugo Winckler (Hebraica October, 1887, page 52), and shows that the canal and tunnel were built by Assuranazirpal, King of Assyria, 884–860 B. C., and restored by Essarhaddon 680–668 B. C. The object of the conduit was to lead the water of the Zab to Nimrud, the ancient Kelaeh.

Berosus states: "When Nebuchadnezzar had received the royal power he surrounded Babylon with a triple wall in fifteen days. He drained the Nahrmalka, an arm of the Euphrates. Above the city Sippara he built a reservoir, 40 parasarp in circumference and 20 fathoms deep, and built gates which could be opened so as to irrigate the plain." In the great East India House Inscription of Nebuchadnezzar, first deciphered by Oppert, we find a full and detailed confirmation of this statement of Berosus.

Diodorus mentions (II, ix., 2) a tunnel built under the Euphrates at Babylon, the existence of which, although believed in by Oppert, is doubted by more recent archæologists.†

In Judea a very ancient tunnel ‡ about one-third of a mile in length, by which water is brought from the Virgin's Pool in the Kedron Valley to the Pool of Siloam, pierces the ridge of what is supposed to be Ophel (a spur of the temple hill which divides the two mountains). It was constructed for the purpose of bringing water into the City of Jerusalem when the surrounding district was in possession of the enemy. In the tunnel there is engraved an inscription ‖ of five lines, which gives

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*Layard, "Nineveh and its Remains," page 57.

†Compare Chaldea, Perrot and Chippiez, Vol. II, pages 58 and 59.

‡The conduit is at first about 16 feet high, but the height gradually lessens until at one place it is not quite 2 feet above the floor of the passage. According to Capt. Claude Conder, R. E., the tunnel is 1 708 yards in length.

‖"The Siloam inscription was accidentally discovered in June, 1880. The inscription is engraved on a recessed tablet cut in the wall of the tunnel, a few yards from its lower end. The latest restoration and translation is as follows:

(Behold the) excavation! Now this is the history of the tunnel. While the excavators (were lifting up) the pick, each to his neighbor, and while there was yet three cubits (to be broken through),.....the voice of one called to his neighbor, for there was (an excess?) in the rock on the right. They rose up,.....they struck on the west of the excavation, the excavators struck each to meet his neighbor pick to pick, and there followed the waters from their outlet to the Pool for the distance of 1 000 cubits and (three-fourths?) of a cubit was the height of the rock at the head of the excavation here."—Cyrus Adler in Proceedings U. S. National Museum.

an account of the engineering difficulties that had to be met. It states that the two *culs-de-sac* where the excavations overlapped, near the middle of the tunnel, were caused from lack of engineering skill.* The inscription is intended to place on record the manner in which this difficulty was obviated.

In one of the mounds at Tello, M. De Serzec found a series of cylindrical pipes or tubes of baked clay, fitted into one another, and formed together a conduit for draining the water from the walls.†

At Mugheir—Biblical Ur of the Chaldees—the cemeteries were drained in the following manner: The pavements carefully laid, were studded with clay tubes fitting into one another and forming a sort of flue, the lower extremity of which opened into a drain; the upper being furnished with a cap, full of holes, acting as a skimmer. ‡ This system of drainage was laid with such skill that it has remained intact to our own day, and according to Loftus || the tombs have been kept so free from water, that the bodies and the furniture are still dry and in good condition.

In the Island of Kos the remains of a circular stone-lined reservoir, 10 feet in diameter and 22 feet deep, have been found, into which water was carried from the springs in the neighborhood. This reservoir is covered with a stone dome terminating in a stone air-shaft. Against the dome earth has been thrown,—the design of this fountain-house being to keep the water pure and cool. This plan is pursued in India and other tropical countries even to this day.

The water-works at Thebes, from which the Cadmea was supplied, are still in existence, although they are believed to belong to the Pelasgian period. But the remains, so far as discovered, indicate that few works of this nature were constructed by the Greeks, whose natural surroundings directed the attention of their engineers to the building of harbors, roads and bridges; and whose religious predilections inspired their architects to design and erect temples for the worship of their deities.

The *emissaria*, canals for drainage or irrigation, are mentioned at an earlier period of Roman history than the aqueducts. In and near the City of Rome there were originally 250 miles of aqueducts, about fifty of

* Isaac Taylor, The Alphabet, Vol. I, page 232.
† Babelon, Oriental Antiquities, page 21.
‡ Quarterly statement Palestine Ex. Fund, 1881, page 197.
|| Records of the Past, Vol. I, New Series.

which were supported on stone arches. A detailed account of them may be found in a work by Frontinus * (A. D. 97), who was a surveyor or controller of the aqueducts during the reign of Nerva. From the details given by Frontinus, Mr. Parker, an English engineer, estimates the total amount of water delivered by these aqueducts to be equal to a stream 20 feet wide by 6 feet deep, constantly pouring into Rome at a fall six times as rapid as that of the River Thames, a volume equivalent to over 300,000,000 gallons per day.

At Porta Furba, near the City of Rome, the remains of five aqueducts may be seen together, at or close to the point where the Anio Vetus must have passed under ground. The Aqua Appia, nearly 10 miles long, was carried underground for nearly 9½ miles. Of the Anio Vetus, 43 miles long, only 1 500 feet were above ground. The Aqua Filichi and Aqua Marcia were over 50 miles in length, and the Anio Novus, greater than all, measured 59 miles, some of its arches being 109 feet high.

The monuments of Roman engineering are not confined to Italy, for in every part of the world that they conquered, from the shores of the Atlantic to the borders of India, from the Baltic to the Desert of Sahara, the engineer of that period has left the remains of his skill and ingenuity. One of the most remarkable of these works was an aqueduct that leads from a stream in France, called the Gier, at the foot of Mount Pila, to the summit of Fourvières. This was constructed to supply the water for the imperial palace at Lugdunum,† the modern City of Lyons. This aqueduct terminated in a stone reservoir, lined with cement, in the walls of which are eight elliptical holes 12 inches high and 9½ inches wide; eight lead pipes descended from these holes into the valley and were carried across the bottom of the stream on an aqueduct bridge 25 feet wide. Some of these pipes were found in a vineyard near the top of Fourvières in the early part of the 18th century, and were described by Colonia in his History of Lyons.

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* Frontinus states that for four hundred and forty-one years after Rome was built, there was no regular supply of water to the city; the water was obtained from the Tiber, from wells and springs; but finding these means inadequate, during the Consulship of Appius Claudius Crassus, the construction of the first aqueduct was begun, and called the Appian Aqueduct, after the Consul.

† Lugdunum was once the capital of Southern Gaul; was built by order of the Roman Senate, B. C. 42, by Lucius Munatius Plaucus. Augustus Cæsar visited it in 15 B. C., and lived there from 12 B. C. to 21 A. D.

Some of the pipes, like the bricks of Nebuchadnezzer, had the name of the maker stamped upon them.

The ability of the Romans to bore tunnels without the aid of explosives, is remarkable. The Grotto of Posilippo near the road to Pozzuoli, near Naples, is a conspicuous example (see Fig. 4). It is 2 316 feet long, 22 feet wide, and has an average height of 89 feet. When or how this stupendous work was accomplished, there is no record. It was regarded as prehistoric by the classic writers of 2 000 years ago. As a piece of tunneling, the emissary of Lake Fucinus is most remarkable. Conceived by Julius Cæsar and executed by Claudius, it leads from that lake to the Liris (Garigliano), more than three miles away. For more than a mile it passes under a mountain, whose summit is over 1 000 feet above the level of the lake. The boring was carried for thousands of feet through carnelian so hard that every inch was worked with a chisel.

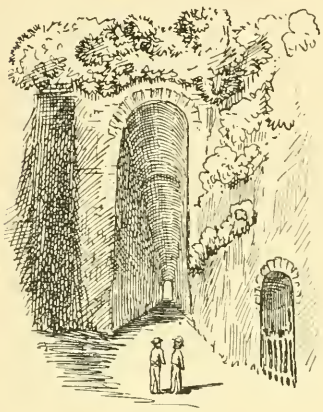


Fig. 4.

The pyramids have long been considered one of the Seven Wonders of the World. The success with which huge blocks of stone were quarried without explosives, is as remarkable as the ability to transport them from the quarries or to place them in proper position in the structure. Of the masonry of the pyramids themselves, it is said by competent engineers who have examined them critically, that it could not be surpassed, even in this day.* Designed, as they were, to last 3 000 years, when the souls of their royal occupants were expected to return again to earth, some of them have survived nearly double that term of years.

It is said that when Napoleon was considering the question of obtaining stone for a bridge, which he once proposed to build across the Nile, the French engineers cast longing eyes at the pyramids; and while making calculations as to the best method of obtaining the stone from these structures, they deplored the fact that the masonry had been so well done, that much time and labor would be consumed in tearing them down.

The Persians in the 5th century B. C. were also proficient in handling

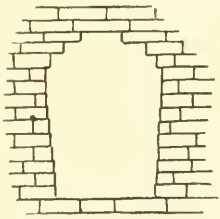
* The inscriptions upon the pyramids, obelisks, sepulchres and temples, particularly those of Isis and Serapis, prove conclusively that the Egyptians employed the chisel and the mallet, and nearly all the tools that are used in our day, for the quarrying and dressing of stone.

heavy bodies. In the palace of Xerxes at Persepolis are to be found blocks of stone 55 feet long and from 6 to 10 feet square, and weighing more than 200 tons.

While considering the wonders of the East, where we are taught to believe was located the cradle of the first great civilization, we must not forget some recent discoveries in what we are pleased to call the New World. I refer to the pyramid, nearly double the size* of Cheops, which was discovered in 1884 in Sonora, Mexico, 50 miles southeast of Madeline. Standing in the midst of a virgin forest, the walls of square blocks of granite carefully tooled and bedded, bear testimony to the skill of that ancient race, whose very name has been forgotten.

The Origin of the Arch.

The history of engineering shows that the arch has been a most important factor in the construction of bridges, tunnels, sewers and



Chaldean Burial Vault, Brick.

Fig. 5.

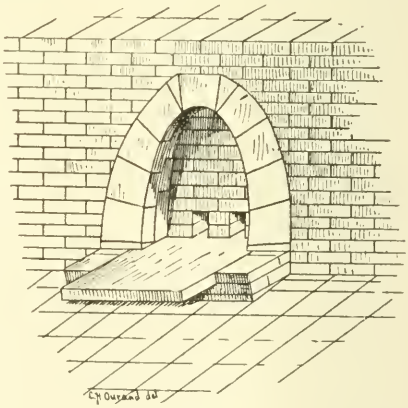


Fig. 6.

palaces. It is the belief of many archæologists that the use of bricks and other small sized materials must have led to the early discovery of the arch in Chaldea. But while the remains of more than one corbeled vault (see Fig. 5) are to be found, no edifice containing the arch with the voussoir, survived the Macedonian conquest. We must look, then, to Assyria for the earliest remains of the true arch. The sewers of Khorsabad (8th century B. C.) are a marvel of ingenuity, for the pointed

* 750 feet high and measuring 4 400 feet round the base with a spiral roadway from base to summit, built at an easy grade, so that vehicles could ascend.

arches which support the earth above them. The Assyrian builders, in order to avoid the keystone, moulded bricks of complicated form (see Fig. 6). The floors of the sewer were composed of limestone slabs extending under the side walls and laid in asphalt. In fact, in every portion of that palace are evidences of engineering skill of no mean order.

Place* describes a true brick arch found at Nineveh in a gateway, erected by Sargon in the 8th century, B. C., that has a span of 14 feet 4 inches. References in the Bible to the arch are found in the 40th Chapter of Ezekiel.

What is regarded by some archæologists as a religious prejudice against the arch in India, led to the construction of a pyramidal roof on the temple of the Sun at Orissa, consisting of many stone blocks weighing 30 tons each, which were hoisted into position on walls 80 feet high. This practice has not been changed by the lapse of time, for, as late as the last century, the roof of the temple at Seringham was laid with long beams of stone across a span of 21 feet.

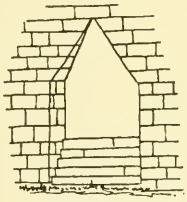


Fig. 7.

Fig. 8.

Remains of Greek structures recently explored continue to verify the belief that the ancient Greek architects were unfamiliar with the principles of the true arch (see Figs. 7 and 8). The arched way through the west wall of Assos † (see Fig. 9), and the portal‡ in the west wall of the same city (see Fig. 10), explored in 1881, are of the corbeled type.

Ancient Harbors.

The Phœnician harbor in front of the Admiral's palace at Utica, built to shelter the galleys from storm, was constructed with great skill. The Phœnicians in the 10th century, B. C., employed civil engineers to

* Ninivi I, pages 170–182.

† Explored by Mr. J. S. Diller, now of the U. S. Geological Survey, to whom I am indebted for the use of the photograph and other information.

‡ Described by Mr. J. Thatcher Clarke, in Papers of the Archæological Institute of America, Classical Series I, from whose pages this illustration was redrawn.

build the ancient and renowned harbors of Tyre and Sidon. These people, 1280 B. C., navigated the Straits of Gibraltar in their own ships, and founded the Port of Cadiz, erecting docks and warehouses there. They controlled the commerce of the world, worked the tin mines of Cornwall and traded everywhere along the Mediterranean coast.

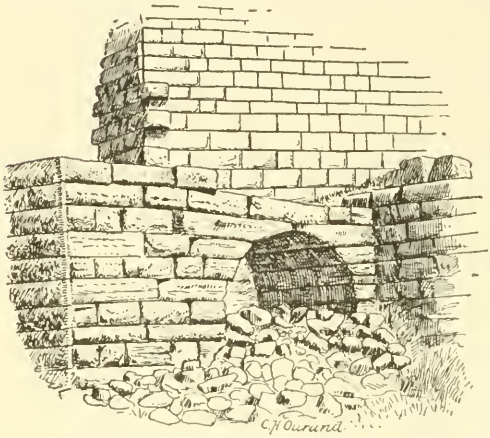


Fig. 9.

The harbor of Piræus is one of the most celebrated in the Mediterranean; and the remains of the stone jetties at the breakwater at Pylos, on the west coast of Messenia, at Methone, south of Pylos, and at Rhodes, testify to the ability of their builders.

The Roman harbors at Centumcella and Ostia, built where no natural opportunities presented themselves, are renowned for the engineering ability displayed in their construction.

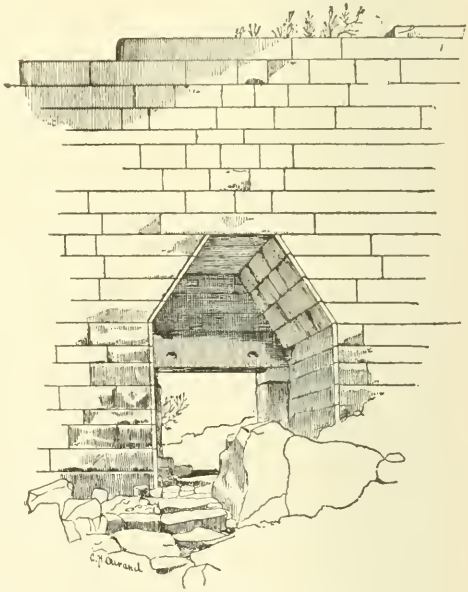


Fig. 10.

The Emperor Claudius had the boldness to direct that the largest ship in the world, which had previously been used to transport an obelisk from Egypt to the Vatican, be used as a caisson. Upon it were built three pillars of stone and pozzuolana cement, which, with the ship, he sunk at Ostia, for the harbor which he was constructing where the Tiber

empties into the sea. Thus twenty centuries ago a subordinate use was found for the most colossal ship of the age, an example which was followed in our era when the "Great Eastern" was employed to lay the Atlantic cable and for other similar uses.

Ancient Roads.

An anonymous writer* thus describes "An Ancient Roadway": "Long before conquering Rome had covered the world with her network of military roads; commerce and war, the sponsors of civilization, had thrown out their lines of communication which bound together the nuclei of culture. The name of one of the earliest cities of primitive times which the Bible makes known to us is Kharran, the "*caravanserai*, or road city."† Hither Abraham had journeyed, following, no doubt, the "*via publica*" of those days, the commercial and military road which bound together the two seats of civilization, the one on the banks of the Euphrates, the other on the banks of the many-mouthed Nile. Few roads can rival, in antiquity or in historic associations, that ancient pathway of culture which connected the capitols of Babylonia and Egypt, and along which was an ever-flowing stream of intercourse. Centuries ago, in a far remote past, the primitive Semite trader had journeyed forth on his long and dreary journey to visit the cities of the "land of the setting sun."

Although no remains exist in Babylon, it is almost certain that a stone bridge‡ across the Euphrates River, which is 600 feet wide, connecting the two portions of the city, was in existence in the 5th century B. C.

Herodotus,§ who examined the causeways of granite over which the stone blocks were transported from the Nile to the pyramids, thought that they were wonderful.

Curtius‖ tells us that "It is the worship of the Gods" which gave rise to road building "and the holy ways were the first artistically constructed by the Greeks." These roads designed for the passage of the festive processions to the great temples of worship, were carefully made. A notable example of the care taken in these matters is to be found in the tramway, the remains of which are the oldest in existence. The con-

* In *The Builder*, 1885.

† Genesis XI, 31.

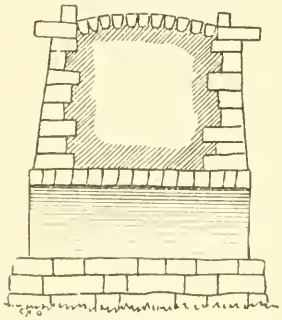
‡ It is described by Herodotus and Diodorus—the latter of whom puts the length at 55 stades, over 3000 feet; undoubtedly an exaggeration, unless the approaches were included.

§ Herodotus, II, 124.

‖ History of the building of roads among the Greeks.

struction was prompted by the superstitious dread of accident to vehicles on the way to the Olympian games. Any mishap *en route* was regarded as an ill omen for those who were to engage in the contests. The road was carefully built of stringers of stone hollowed out to the proper gauge to fit the chariot wheels.

The superb highways which the Roman emperors constructed, gave them power to move their armies with rapidity to the foreign settlements, against which attacks were expected from hostile barbarians. It was a common saying that "all roads lead to Rome," and the remains of Via Appia, Via Aurelia, Via Latina, and Via Ostiensis testify to the care and skill with which these highways were built. (See Fig. 11.)



Section of Roman Road through Culvert.

Fig. 11.

The fortifications which they erected; the engines of war which they invented and introduced, show remarkable inventive ability. For demolishing walls of masonry, the tormenta or battering ram was used with as much success in their day, as it could be in ours. And the catapult for casting projectiles, some of which Vitruvius states weighed 2 000 pounds, was the most efficient engine of its kind before the discovery of gunpowder.

The remains of Roman military roads are found in Bavaria and in Great Britain where they are called ridgeways. Watling street in London, is said to occupy the site of one of these old roads. The boundaries of the ancient Palmyrean Empire in Western Asia, abounds in Roman ruins.

As Bucholz has very aptly said: "Wherever the conquering arms of the Romans were carried, through Gaul into Germany and over to Britain, through Greece into Asia Minor and India, to the very gates of Cathay, the engineer followed, and often led the way."

Ancient Metallurgy.

The limits of this paper admit of only brief references to the ability which the ancient metal workers displayed even in the earliest times. Babelon* asserts that "the Chaldeans could work in bronze as skillfully

* Manual of Oriental Antiquities, page 35.

as in stone," and that in recent explorations were found "statuettes, bas-reliefs in repoussé, vases and utensils of every sort, weapons and ornaments, so that there is no use of the precious metals, or of iron and bronze, to which they were not put by the industry of the Ninevite craftsmen." At Tello, M. de Sarzec found the remains of many doors that turned on pivots, which rested in cavities in hard stone blocks, hollowed out in the form of a conical cup. "To prevent the wooden pivot of the doors from wearing out too rapidly, it was enveloped in a metal (bronze) sheath that took the form of a funnel, and which was fixed to the wood by nails."*

M. Goguet † states that "the art of forging metals without any doubt, was known in Egypt and some parts of Asia, in the most distant times. We see arms of metal in use in Palestine a few ages after the flood. Moses says that Abraham drew his sabre to sacrifice his son Isaac." Many facts relating to metals, the places where they were found, and the manner in which they were wrought, are recorded in the book of Job. Iron which was once regarded as a precious metal ‡ by some of the most ancient nations, was applied to subordinate uses by the inhabitants of Nineveh. Place describes § a collection of hooks, grappling irons, chain cables, picks, mattocks, hammers and plough shares, weighing over 150 tons, that were found at Khorsabad, hung on the walls where they were placed eight centuries before our era.

From the sharpness of many ancient coins, it is manifest that the die-sinker was not only able to work in hard metals, but that he was possessed of no mean mechanical ability in the construction of the presses by which the coins were struck.

We are indebted to Aristotle himself for an actual account of the way in which the Greeks made steel in the 4th century B. C., proving them to have been also acquainted with the art of melting iron. The passage (III, 7), as translated by Martin Lister, reads: "Wrought-iron itself may be cast so as to be made liquid, and to harden again; and thus it is they are wont to make steel; for the scoria of iron subsides, and is purged off by the bottom; and when it is often defecated and

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* *Ibid*, page 17.

† Of the Discovery of the Working of Metals, Book II.

‡ "Iron was looked upon as a precious metal; neither arms nor utensils or tools were made of it; it was employed almost exclusively for personal ornaments, such as rings and bracelets."—Perrot and Chipiez Chaldea, I, 30.

§ Ninivi I, pages 84, 89.

made clean, this is steel. But this they do not often, because of the great waste, and because it loses much weight in refining; but iron is so much the more excellent the less recrement it has." Steel was made by this method in Germany as early as the 16th century.

China possessed the art of working fluid cast-iron at a very remote period. The working of iron in the mountains of India* was carried on many centuries before the Christian Era. It would almost seem that the "Iron Age" is a misnomer.

Engineering of the 17th and 18th Centuries.

Engineering development, since the beginning, has been influenced by the outgrowth of natural surroundings. In Greece, Italy, Switzerland and France the mountains, streams and gorges turned the attention of the engineer toward tunnels and bridges. So in Holland and Belgium, low and flat, the continual battle against floods developed a race of engineers with special skill in drainage and dyke building; while in England, surrounded on all sides by a stormy sea, thought was directed to light-houses, harbors and docks.

During the Dark Ages, from the downfall of the Roman Empire in the 5th century until the beginning of the 16th, the sciences were almost lost, being practiced only by the monks and other religious organizations. To the Freemasons, Brothers of the Bridge, and other secret societies, the world is indebted for the few structures that were erected during those unprogressive centuries.

The civil engineer reappeared upon the arena about the middle of the 17th century, in response to the demand for the drainage of the marshes and submerged lands of Italy, although Ferario describes a masonry bridge that was completed across the River Adda, in Northern Italy, in 1377, with a segmental arch 237 feet span and 68 feet rise. This arch is 22 feet wider than the largest arch now in existence—that over Cabin John Creek, near the City of Washington.

It has been said of Holland † that "the Dutch made their own land out of the mud of the rest of Europe." So for centuries our Dutch ancestors have been steadily at work during years of war and times of peace, adding to the area of their country by building canals and dykes

* In the Temple of Kuttub, near Delhi, is standing to-day a forged iron pillar, upward of 16 inches in diameter and over 50 feet long.

† Smiles' "Lives of the Engineers," page 392.

and reclaiming land. It was in 1574 that William of Orange took advantage of this peculiarity of the country by flooding all the land in the vicinity of Amsterdam, in order to defend that city from a land attack by the Spanish. And as Holland gradually provided herself with her magnificent system of artificial water roads, which made every important city in her borders a seaport; her industrial energy was rewarded as the nation increased in prosperity to a remarkable degree, and attained a position of power among the nations of Europe, developing among her people traits of character which were inherited by those who were afterward to found the metropolis of the New Republic.

In Russia, about the end of the 17th century, Czar Peter began to lay the plans for a system of inland navigation to connect the new City of St. Petersburg with the Caspian Sea, and to place Moscow upon another line by forming a canal between the Don and the Volga, 30,000 men being set to work under Captain John Perry, a native of Gloucester. It was during the beginning of these improvements, in 1699, that the local nobility (or boyars), near Moscow, solemnly stated, "That God had made the rivers to flow one way, and it was presumption in man to think of attempting to turn them in another."

Engineering may be said to have had its beginning in France during the reign of Louis XIV (1638–1715), who in 1661, through the instrumentality of John Baptiste Colbert,* his Comptroller General of Finance, began to devote attention to commerce and manufactures and to inaugurate the system of internal communication in France by land and water, which was so necessary to its development.

Soon after Colbert received his portfolio the systematic improvement of the public highways leading to Paris was inaugurated. The Languedoc Canal, connecting the Mediterranean with the Atlantic, without passing the rocks of Gibralter, 150 miles long, with its summit level 600 feet above the sea, although not finished until 1681, was projected in 1666, during his ministry. He devoted much time and thought to the detail of paving and lighting the City of Paris, and it was largely through his influence that the Academy of Inscriptions was founded in 1663;† the Academy of Sciences in 1666, and that of Architecture in 1671.

* Colbert claimed descent from a Scotch family which settled in France during the latter part of the 16th century.

† Richelieu had founded the French Academy in 1635, and established the first French scientific paper, "The Gazette of France." He also founded the Observatory of Paris, 1667–71.

The system of building the great fortifications upon the frontier of France was begun in 1677 by Vauban, who was appointed that year to the new office, "Commissary General of Fortifications," especially created for him by Louis XIV. Vauban displayed remarkable ability, first in planning fortifications, which were regarded as impregnable; secondly, in devising methods by which no fortification could be taken.

In 1729 General Belidor* while Professor at the Artillery School at La Fire, published a treatise ("La Science des ingenieurs dans la Conduite des traveaux de fortification et d'architecture civile") upon the Science of Engineering. In 1758 he became director of the arsenal at Paris, and a year or two later Royal Inspector General of Engineering.

The wars in which France engaged, together with the financial condition of that country from 1680 to the death of Louis XIV (1715), was discouraging to internal improvement and engineering enterprise. Nor did the first years of the reign of his successor, Louis XV, when John Law was permitted to establish the Bank of France upon a paper money basis, and to organize the "Mississippi Joint Stock Company" with its Grant of Louisiana, add to the material development of the commerce of that nation, almost constantly at war for the next thirty years. During this period, however, L'Ecole des Ponts et Chausses was established (1720), and from it has been graduated many mathematicians and practical engineers.

In the 17th and first half of the 18th centuries great progress was made in France in the art of bridge building, so that when the new Westminister Bridge, across the Thames, was to be built, Labelye, a Swiss engineer, who had been very successful in constructing bridges in France, was called to take charge of the work.

For a brief seven years after the treaty of Aix-la-Chapelle in 1747, France was given another opportunity to advance internal improvements —to strengthen her navy, her merchant marine, and to recruit her corps of mariners. This was the period (1755-60) of French naval glory. Soon after the peace of Paris (1763), L'Ecole Militaire was established under the patronage of the Duc de Choiseul † in the royal palace of Fontainebleau during the latter part of the reign of Louis XV. And it was under the shadow of the walls of this historic palace that many of the French officers, who took an active part in our Revolution, and

* Bernard Forest de Belidor (born Catalonia, 1693; died Paris, 1761). French Military and Civil Engineer and author of works on Mathematics, Bombardment, Military and Civil Engineering and Hydraulic Architecture.

† Etienne Francois Choiseul, born 1719; died 1785. Minister of Foreign Affairs, 1758.

Louis XV influenced by Madame Pompadour always regarded this palace with disfavor and refused to occupy it with his court.

the bloody scenes of strife in France during the next decade, learned their first lessons in military engineering.

It is interesting to note that Napoleon Bonaparte's knowledge of engineering methods led to his first promotion, when only twenty-nine years old, by General Barras, who gave him the command of the artillery of Paris in October, 1793, "because he knew how to make and use a map"; and for a similar reason, Ponté Coulant, a year or two later, placed him at the head of the *Cabinet de Topographie.*

In 1803 "The First Consul"* founded the University of France; and three years later, (1806), he removed the Military School from Fontainebleau to St. Cyr, made famous 117 years before, when the school for the daughters of French noblemen was established by Madame de Maintenon. From the beginning, L'Ecole Speciale Militaire de Saint Cyr has ranked high among all nations; and it has furnished France and the world with many distinguished military and civil engineers.

I have gone into the "Beginnings of Engineering" in France at some length, owing to the fact that the progress of engineering science in America during 1775 to 1825 was largely directed by Frenchmen who came to this country at the solicitation of our Government.

Although England has produced eminent engineers, skilled in the construction of canals, harbors and light-houses, the technical knowledge that lay dormant among her people, was not manifested until the steam engine was introduced. At the time when Holland had made great progress in internal improvement and systems of water communication, and when France, Germany, and even Russia had opened up important lines of inland navigation, there was not a single canal in all England† and the common roads were about the worst in Europe.

* The period of the Consulate, 1800–04, was the most glorious and commendable part of Napoleon's career. He devoted himself especially to every project that could benefit and protect France, doing probably the work of a dozen able men.

† The lack of capable engineers in England in the 16th and 17th centuries is thus described by Smiles: "Our first lessons in mechanical and civil engineering were principally obtained from Dutchmen, who supplied us with our first wind-mills and pumping-engines.

"When an engine was required to pump water from the Thames for the supply of London, Peter Morice, the Dutchman, was employed to erect it. Holland even sent us the necessary laborers to execute our first great works of drainage. The great level of the fens was drained by Vermuyden, and another Dutchman, Freestine, was employed to reclaim the marsh, near Wells, in Norfolk. When a new haven was required at Yarmouth, Joas Johnson, the Dutch Engineer, was employed to plan and construct works, and when a serious breach occurred in the banks of the Witham, at Boston, Matthew Hake was sent for from Gravelines, in Flanders, and he brought with him, not only the mechanics, but the manufactured iron required for the work."

"The art of bridge building had sunk so low in England, about the middle of the last century, that we were under the necessity of employing the Swiss engineer, Labelye, to build Westminster Bridge. In short, we depended for our engineering, even more than we did for our pictures and our music, upon foreigners.

"In 1642 the dykes in the embankment around Hatfield Chase, in Lincolnshire, were broken by the enemies of the Dutch settlers, so that the reclaimed lands were inundated, causing a loss of £20 000 in a single night."

The water supply of the City of London was obtained from wells, as late as the end of the 15th century. The water-carrier was an important element in domestic economy until 1582, "when Peter Morice, a Dutchman, undertook, as the inhabitants could not go to the Thames for their water, to carry the Thames to them," and then a pumping-engine, driven by water-power, was put in the first arch of the old London bridge. Wooden logs were being used for the conduits, the pipes carrying the water into the houses being made of lead. In 1609, Hugh Myddleton began the construction of the New River Water-works to supply London with water, the works being completed in 1613.

In the history of corporations it is interesting to note, that King James I, in 1612, became a full partner in this enterprise, by no means a small one for the times, as the total cost of the works (the aqueduct being 10 feet wide, 4 feet deep, and 39 miles long) was £8 610, and for which the King furnished his share from his private purse. In 1720, an act was obtained empowering certain persons to make the rivers Mersey and Irwell navigable from Liverpool to Manchester. By the use of weirs, locks and flushes a moderate improvement in the navigation was effected. But these improvements were confined to clearing out the channels of existing rivers and not to the making of new and direct navigable cuts between the cities.

In 1737 Parliament passed the first Canal Act to make navigable the Worsley Brook, near Manchester, but it was not until the year 1760 that Brindley began his first canal for the Duke of Bridgewater.

Origin of the Title "Engineer."

The earliest use of the term "Engineer,"* that I have found is in Shakespeare, where Hamlet (III, 4) speaks of the engineer hoist with his own petard.

The charter of the British Institution of Civil Engineers defines engi-

* We are told in Rees's Cyclopædia, Vol. 13 (published about 1810), that "Engineer or engineering in its general sense is applied to a contriver or maker of any kind of useful engine or machine." "In its more proper sense, it denotes an officer of the army or fortified place whose business it is to contrive or inspect attacks, defenses, works, etc." "The term engineer is said to be of modern date, and to have been first used in the year 1650, when one Captain Thomas Rudd had the title of Chief Engineer to the King." "In 1634, an engineer was called a camp-master general, and sometimes engine-master, being always subordinate to the master of the ordnance." "An engineer should be an able and expert mathematician, particularly versed in military achievements and gunnery." "Civil engineers are a denomination which comprises an order or profession of persons highly respectable for their talents and scientific attainments, and eminently useful under this appellation, as the canals, docks, harbors, lighthouses, etc., amply and honorably testify."

neering * as "The art of directing the great sources of power in nature for the use and convenience of man, as the means of production and traffic in States both for external and internal trade * * * * * *" as applied:

First.—In the construction of roads, bridges, aqueducts, canals, river navigations and docks for internal intercourse and exchange.

Second.—In the construction of ports, harbors, moles, break-waters and light-houses.

Third.—In the art of navigation by artificial power for the purpose of commerce.

Fourth.—In the construction and adaptation of machinery.

Fifth.—In the drainage of cities and towns.

Thus, from a subordinate military position upon the staff of a general, the title of engineer has been extended to include all who, by the use of scientific methods of thought, utilize the experiences of the past to overcome the natural forces in the interest of industrial or mechanical progress. From the reports of John Smeaton, F. R. S. (1797), we learn that civil engineering became a profession in England about 1760. It is said of Smeaton, who was the first expert witness called before English courts in matters relating to his profession, that he was the first to use the title "Civil Engineer,"† when he signed his name as such to testimony that he gave in an important case.

History of Engineering in the United States.

The first canal constructed within the present limits of the United States, was, according to some accounts, a short line built by Lieutenant-Governor Colder, in Orange County, N. Y., in 1750, for transporting stone.

Before Independence was declared, the project of providing an artificial junction between the waters of the Susquehanna and the Schuyl-

* In the Century Dictionary, recently published (1889 edition), engineering is defined as "The art of constructing and using engines and machines; the art of executing civil and military works which require a special knowledge or use of machinery, or of the principles of mechanics."

† See discussion by Mr. Clemens Herschel, to whom I am indebted for calling attention to these facts.

kill,* led Franklin, in a letter† written in 1772, to Mayor Rhodes of Philadelphia, to pay a high tribute to the profession.

At a session of the Council of the Province of New York, September 1st, 1774, a resolution was passed to the effect that it "be very expedient that the limits of this and the Province of Pennsylvania be speedily ascertained and marked out."

This idea was concurred in by the Pennsylvania authorities, and the initial point was established by a commission comprised of Major Samuel Holland, a British officer, on behalf of New York, and David Rittenhouse, of Pennsylvania, who in a report, dated December 14th, 1774, and presented January 25th, 1775, stated that they had determined "the beginning of the 43 degree of North Latitude, on the Mohawk or Western branch of Delaware."

The American Society of Civil Engineers, by resolutions spread upon its minutes, soon after the celebration of the Centennial of the Constitution, at New York City, April, 1889, has made official record of the fact that Washington "before he became a soldier, long before he entered on his career as a statesman, his inclination led him in the direction of engineering." And that "during his official life, he was careful to intrust work requiring engineering skill, to educated and experienced engineers."

That Washington and his advisors recognized the importance of having engineers appointed for the Continental Army, early in the

* Probably the first enterprise of the kind seriously discussed in the colonies, as William Penn had referred to the subject in the century before,

† Letter is dated London, Aug. 22, 1772. Franklin writes: "I am glad my Canal Papers were agreeable to you. I fancy work of that kind is set on foot in America. I think it would be saving money to engage, by a handsome salary, an engineer from here, who has been accustomed to such business. The many canals on foot here under different great masters, are daily raising a number of pupils in the art, some of whom may want employment hereafter, and a single Mistake thro' Inexperience in such important Works, may cost much more than the Expense of Salary to an ingenious young Man already acquainted with both Principles and Practice. This the Irish have learned at a dear rate in the first attempt of their great Canal, and now are endeavoring to get Smeaton to come and rectify their Errors. With regard to your question, whether it is best to make the Schulykill a part of the Navigation to the back country, or whether the difficulty of that River subject to all the inconveniences of Floods, Ice, &c., I can only say that here they look on the constant Practicability of a Navigation, allowing Boats to pass and repass at all times and seasons, without Hindrance, to be a point of the greatest importance, and therefore, they seldom or ever use a river where it can be avoided. Locks in rivers are subject to many more accidents than those in still water canals; and the carrying away a few locks by the Freshets of Ice, not only creates a great expense, but interrupts business for a long time till repairs are made, which may soon be destroyed again, and thus the carrying on a course of business by such a navigation be discouraged, as subject to frequent interruptions. The Toll, too, must be higher to pay for such repairs. Rivers are ungovernable things, especially in Hilly Countries. Canals are quiet and very manageable. Therefore they are often carried on here by the Sides of the Rivers, only on Ground above the Reach of Floods, no other use being made of the Rivers than to supply occasionally the waste of water in the canals.

"I warmly wish success to every attempt for Improvement of our dear country, and am with sincere Esteem,

"Yours most affectionately,

"B. FRANKLIN."

struggle for independence, there is no doubt, for we find that on June 16th, 1775, the Continental Congress resolved: "That there be one chief engineer at the grand army, and that his pay be $60 per month; that two assistants be employed under him, and that the pay of each of them be $20 per month; that there be one chief engineer for the army in a separate department and two assistants under him; that the pay of the chief engineer be $60 per month, and that of his assistants each $20 per month.

"The pay of chief engineer and assistant engineer, was what the grades of colonel and captain received at that time, and the officers appointed in the army under this resolution were commissioned according to those ranks. This practice only continued for a short time and by April, 1776, we find that assistant engineers were commissioned with as high rank as lieutenant-colonel."

December 27th, 1776, Congress resolved: "That General Washington be vested with full, ample and complete powers * * * to raise, officer and equip 3 000 light horse, three regiments of artillery and a corps of engineers and establish their pay." And early in 1777, four officers from the Royal Corps of Engineers of the French army were added to the Continental army, Brig.-General Louis le Begue du Portail taking precedence of all other engineers in the service. The first companies of engineer troops in the American army were established under the resolution of Congress, May 7th, 1778. General du Portail continued to be a commanding officer of the corps of engineers until the close of the Revolution.

After the Revolution attention was directed to the establishment of boundary lines between the States. Captain Thomas Hutchins, who was appointed Geographer General of the United States in 1781, held that position until his death, 1789. He was succeeded by his deputy, Andrew Ellicott, one of the Commissioners, in running the western boundary line of Pennsylvania in 1785, and in extending Mason and Dixon's line, 1784. In 1801, the office of Surveyor-General of the United States was created and Andrew Ellicott was appointed to that position.

After peace was declared in 1783, attention was also directed to internal improvements, especially in the Southern States. Brindley's success in England demonstrated the feasibility of canal construction and many canals were projected in this country. The first charter under which active operations were prosecuted, of which I have found record,

was granted when the James River Company was incorporated by the Legislature of Virginia on January 5th, 1785. The company constructed a canal around the falls of James River, extending from the City of Richmond to Westham, for the purpose of improving the navigation of the James River, and afterward improved the bed of the river by sluices as high up as Buchanan. This canal was subsequently enlarged and extended, mainly by State aid.

The Dismal Swamp Canal, commenced in 1787, under a joint charter of Virginia and North Carolina, was opened in 1794, George Washington and Patrick Henry being shareholders in the company. During the war of 1812–14 this canal afforded water channel of communication for American boats being free from the attacks of British cruisers.

A charter was granted on June 25th, 1792, to "the proprietors of the locks and canals on the Merrimac River,"* and this company opened a line in 1797, 1½ miles long.

The Carondelet Canal was constructed by Governor Carondelet, in Louisiana, about 1794, partly as a drainage canal for the City of New Orleans. The citizens contributed the labor of a large force of slaves to aid in the undertaking.

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* Mr. James B. Francis, M. Am. Soc. C. E., writes from Lowell, Mass., August 25th, 1890, as follows:

DEAR SIR:

Since writing to you in reply to your letter of July 29th last, I have been looking up the early engineers in this part of the country.

In 1793 a charter was granted by the State of Massachusetts, incorporating the proprietors of the Middlesex Canal, to construct a canal from the tide-water near Boston to the Merrimac River at Chelmsford, Mass., a distance of about 25 miles. A board of directors was chosen who appointed a committee to carry on the work. In a report before me, it is stated: "Here the committee was met by an almost insurmountable difficulty; the science of civil engineering was almost unknown to any one in this part of the country. They were, however, determined to persevere." After some explorations, "March 1st, 1794, the directors passed a vote appointing Loammi Baldwin to repair to Philadelphia and endeavor to obtain Mr. Weston's (an English engineer) assistance in conducting the canal. If he cannot come, then that he endeavor to obtain some other person who shall be recommended by Mr. Weston, and that said agent be authorized to write to Europe for some suitable person for the undertaking if none can be found elsewhere." Mr. Baldwin engaged Mr. Weston, who arrived about the middle of July, and made a full report in August, 1794.

"The work was prosecuted with great caution from the commencement of the year 1803, at which time it was so far completed as to be navigable from the Merrimac to Charles River."

From the above I infer that Mr. Weston (I cannot give his initials) was the first person who was called a civil engineer, employed in Massachusetts and probably in New England.

Loammi Baldwin lived at Woburn, on the line of the canal about ten miles from Boston, and was the intimate friend of Benjamin Thompson, afterward Count Rumford, a native of the town. Mr. Baldwin was one of the directors of the company, and appears to have taken an active part in the construction of the canal; three of his sons became prominent engineers. Loammi was the engineer of the dry dock in the Charlestown Navy Yard, constructed about 1830, and believed to be the first work of the kind in the United States, and is still in use. James F. was the chief engineer of the Boston and Lowell Railroad, opened for traffic in 1835, and of the Boston Water Works. George Rumford, the youngest son, named after his father's friend, Count Rumford, was of a retiring habit and of delicate health, he died about two years since in his ninety-first year. He resided for some time in Quebec, and was the engineer of the water works there.

Respectfully yours,

(Signed) JAMES B. FRANCIS.

J. E. WATKINS,
United States National Museum,
Washington, D. C.

A canal 22 miles long was built in South Carolina in 1802, to connect Charleston Harbor with the Santee River, at a cost of $720 000.

A work entitled an "Historical Account of the Rise, Progress and Present State of the Canal Navigation in Pennsylvania" was published in Philadelphia in 1795, by direction of the President and Managers of the Schuylkill Navigation Company, in which Robert Morris, the president of the company, states that in 1789 a few citizens of Pennsylvania had united "by the name of the Society for Promoting the Improvements of Roads and Inland Navigation," and that the number of members has since increased to more than one hundred, residing in various parts of the State.

March 20th, 1794, Congress authorized President Washington to construct fortifications for the protection of certain harbors along the coast. As there were few engineers in America, the President directed the temporary appointment of a number of French engineers, some of whom had been in the Revolutionary Army. Among them were John Jacob Ulrich Rivardi, John Vermonet, Nicholas Francis Martinon, Paul Hyacinte Perrault, Stephen Rochefontaine, Charles Vincent, Peter Charles L'Enfant, who were appointed and entered upon the discharge of this duty between the 25th of March and the 12th of May of the year 1794.*

This corps was stationed at West Point where the Military School had been organized, the Secretary of War having been authorized to "provide necessary books, instruments and apparatus." In 1796 these books, etc., were destroyed by fire and the school was not reopened until 1801, under direction of Major Jonathan Williams, Commandant,† Andrew Ellicott, Surveyor-General of the United States, being appointed Professor of Mathematics, and so continuing until his death in 1820. In a communication to President John Adams, January 31st, 1800, James McHenry, Secretary of War, speaking of the duties of the Engineer Corps states: "We must not conclude that the service of the engineer is limited to constructing fortifications. This is but a single branch of the profession; their utility extends to almost every department of war; besides embracing whatever respects public buildings, roads, bridges, canals, and all such works of a civil nature."

By Act of March 16th, 1802, in which the military peace establishment was fixed, it was provided in Section 27: "That the said Corps,

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*See Historical Sketch Corps Engineers, page 6.

† Rochefontaine had been appointed Commandant of the Corps in 1795.

when organized, shall be stationed at West Point, in the State of New York, and shall constitute a Military Academy; and the engineers, assistant engineers and cadets of said corps shall be subject at all times to duty in such places and on such service as the President of the United States shall direct."

At this time the project of constructing a national road from Washington to the Ohio was actively discussed. The ordinance of 1787 under which the North West Territory was established, contained a clause which stipulated that 2 per cent. of the proceeds of all land sales should be devoted to its construction. The act providing for the survey and construction of the National Road was not passed, however, until 1806, when during the administration of Thomas Jefferson systematic surveys and exploitations of the great West, were inaugurated and carried forward with zeal and intelligence. The construction of this road was important, since it settled, after a long contest, the important constitutional question, that it was lawful to use the nation's money for the construction of lines of inter-communication, and for the improvement of rivers and harbors. This road was opened 130 miles to Wheeling, in 1820, the cost to that time being about $1 000 000.

The necessity of a survey * of the coast of the United States was discussed during the latter part of the last century. The necessity for better charts had been recognized for many years by all navigators who approached our shores, but no law authorizing any survey was passed until that of February 10th, 1807, upon the recommendation of Thomas Jefferson. It is stated in a recent report of the Coast Survey that "the plan adopted for its execution was the one proposed and previously foreshadowed by Mr. Ferdinand R. Hassler, who came to America in the fall of 1805, being a man of fine scientific attainments and engineering experience in the triangulation of the Canton of Berne, Switzerland." He was a protegé of Dr. Robert Patterson, President American Philosophical Society, and Albert Gallatin, Secretary of the Treasury.

In 1811 Hassler was sent to England to have instruments constructed from designs prepared by him. He was detained there by the war until 1815, when he returned and was appointed Superintendent of the Survey, August, 1816, but in April, 1818, appropriations were suspended.

* The survey of the coast of the United States was probably suggested by the Trignometrical Survey of Great Britain, which was prosecuted with great vigor under General Roy, beginning about 1790. Compare "The Origin of the National Scientific and Educational Institutions of the United States, by Dr. G. Brown Goode." Papers of the American Historical Association, April, 1890, pages 44 and 45.

Under the Act passed April 29th, 1816, General Simon Bernard was placed in charge of the Board of Engineers for Fortifications,* and virtually of West Point Academy. Soon after Bernard's appointment appropriations for the Coast Survey were suspended, and tactics, text-books, etc., were introduced at West Point, requiring a more thorough knowledge of the French tongue than heretofore; hence an extended course in the study of that language was organized. General Bernard and the officers associated with him were conversant with engineering progress abroad, and consequently were looked upon as authorities on all such subjects here, and their opinions were eagerly sought by capitalists, projectors of railways and canals, and by statesmen and public minded citizens who were anxious to hasten internal improvements in America. From these sources great pressure was brought to bear upon Congress during the latter part of the administration of President Monroe.†

Under the Act of April 30th, 1824, the National Board of Engineers for Internal Improvement was organized, and continued until August 10th, 1831, when General Bernard, who had some disagreement with President Jackson, resigned and returned to France. During these eight years many of the Engineer Corps were engaged in exploration, preliminary surveys for canals and railways, and in the preparation of plans for the construction of bridges, roadbeds and tracks.‡

Of five hundred and seventy-two men graduated from the West Point Military Academy from 1802–29, forty-nine were appointed chief or resident engineers on railways or canals previous to 1840.‖

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*The reports made by this Board form the basis of the system of permanent fortifications along our coast.

† April 30th, 1824, it was enacted: That the President of the United States is hereby authorized to cause the necessary surveys, plans and estimates to be made of the routes of such roads and canals as he may deem of national importance in a commercial or military point of view, or necessary for the transportation of the public mail, designating in the case of each canal, what parts may be made capable of sloop navigation; the surveys, plans and estimates for each, when completed, to be laid before Congress.

SEC. 2. That, to carry out the objects of this act, the President be, and he is hereby, authorized to employ two or more skillful civil engineers, and such officers of the Corps of Engineers, or who may be detailed to do duty with that corps, as he may think proper, and the sum of thirty thousand dollars be, and the same is hereby, appropriated, to be paid out of any moneys in the Treasury not otherwise appropriated. (See Hist. Sketch Corps Engineers, page 19.)

‡ See also Extract from Vol. I, Cullum's Biographical Register of Graduates of West Point, in Appendix.

‖ Prominent among them were: Major John Wilson, U. S. A., who had charge of the preliminary surveys of the Camden and Amboy and the Columbia and Philadelphia Railroads; and with the construction of the latter road from 1827 until his death in 1833. (1.) Joseph G. Swift, Engineer, New Orleans Railroad. (71.) John James Abert, Engineer, Louisville Canal; afterwards Chief of Topographical Engineers. (172.) William G. McNeill, Chesapeake and Ohio Canal; Baltimore and Ohio, Baltimore and Susquehanna, and Boston and Providence Railroads. (214.) George W. Whistler, in charge of engineering works in Russia; and Engineer, Paterson and Hudson Railroad. (291.) General William Cook, for many years Chief Engineer, Camden and Amboy Railroad. (297.) William C. Young, Chief Engineer of several New York railroads. (302.) Isaac R. Trimble, Chief Engineer, Boston and Providence Railroad. (337.) David B. Douglas, Chief Engineer, Morris Canal. (361.) Dennis M. Mahan, distinguished engineer and author. (370.) John M Fessenden, Chief Engineer, Boston and Worcester Railroad. (516.) Stephen H. Long, Engineer, Baltimore and Ohio, Portage, Charleston and Memphis, and several other roads.

At the next session of Congress (1832) after General Bernard's resignation and return to France, the act of 1807 establishing the Coast Survey was revived, and Mr. Hassler was placed again at its head; but from 1832 to 1836 this survey was under the charge of the Navy Department. In the Centennial (1876) Report of the Treasury Department, Vol. XI (page 114), it is stated that "while the Coast Survey owes its present form, and perhaps its existence, to the zeal and scientific ability of the first Superintendent," the organization, as it exists to-day, complete in every branch, is the creation of Alexander Dallas Bache.*

"The survey may be said to have commenced in 1832, and between that date and the close of 1843, the Fire Island base had been measured; a network of triangles, primary and secondary had been extended over the coast from Point Judith to Cape Henlopen and the Chesapeake, and the topography and hydrography had made commendable advance within the same limits."

In 1845 the Atlantic coast was divided into sections, which work was carried on simultaneously; 1849, Pacific coast similarly divided.

The original intention of having the West Point Military Academy directly under the charge of the officers of the Engineer Corps as teachers, professors, etc., could not be fully carried out from the fact that these officers were assigned to duty in various States and districts, so that it became necessary to appoint instructors from various walks of life, but the charge and superintendency of the Military Academy of West Point remained in the Corps of Engineers until July 13th, 1866.

June 22d, 1831, by a regulation of the War Department the Topographical Bureau of the Engineer Department was constituted a separate bureau of the service.

In the report of Chief of Topographical Engineers, 1835, it will be found that the following officers were assigned to civil duty:

Lt.-Col. J. Kearny, the survey for railroad on eastern shore of Maryland; Lt.-Col. S. H. Long, the survey for railroad, Belfast, Me., to Quebec, Canada and from Merrimac River to the Connecticut River;

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* Superintendents of the United States Coast Survey: Ferdinand R. Hassler, August, 1816, to April, 1818; Ferdinand R. Hassler, August, 1832, to November, 1843, died; Alexander D. Bache, December, 1843, to February, 1867; Benjamin Pierce, February 26th, 1867, to February, 1874; Carlisle P. Patterson, February 17th, 1874, to August 17th, 1881, died; J. E. Hilgard, December 22d, 1881, to August 7th, 1885, resigned; F. M. Thorn, July 24th, 1885, to July 1st, 1889, resigned; T. C. Mendenhall, July 9th, 1889; now in charge.

Maj. W. G. McNeill, superintending construction of Long Island Railroad; Maj. J. D. Graham, surveying railroad, Pensacola, Fla.; Capt. W. G. Williams, surveying projected railroad, Charleston to Cincinnati, O.

Thus it will be seen that five of the ten officers in the Corps of Topographical Engineers were assigned to duty not connected with the army. Of the thirty-five projects in which the Corps of Topographical Engineers were engaged in 1835, fifteen were canal and railway surveys in the various States.*

Before the establishment of the Military Academy at West Point (1801), the few prominent American engineers were men of general education and scientific attainments who received no defined engineering education; but obtained the information, which guided them in their work, from the reports of scientific societies, and the very scant supply of engineering literature, then extant. And a similar condition of affairs prevailed in England.

Among the early American civilian engineers were Thomas Hutchins, the first Geographer-General, and Andrew Ellicott, the first Surveyor-General of the United States, previously alluded to; John Stevens of Hoboken, N. J., who published a most valuable pamphlet in 1812, showing the advantages of a railway over the canal; James Geddes† who was the first engineer engaged on the Surveys of the Erie Canal, 1811; General Andrew Porter,‡ a pupil of Rittenhouse, a Boundary Commissioner and Surveyor-General of the State of Pennsylvania; Hon. Benjamin Wright, Chief Engineer Erie Canal in 1817, and of the Chesapeake and Delaware and the James River Canals, also of the Delaware and Hudson, 1825, and of the Erie Railroad in its beginning, Canvass White, Chief Engineer Erie Canal, 1818, Union and Lehigh Canals, 1825; Delaware and Raritan and Morris Canals, 1830, and of other important works; and John L. Sullivan of Boston, Chief Engineer Delaware and Hudson Canal, 1824.

Although America depended largely upon the West Point Military Academy for civil engineering talent in the early part of the century,

* American State Papers, Vol. II, Military Affairs, page 198.

† See "Laws of New York in Relation to the Erie and Champlain Canals, together with the Annual Reports of the Canal Commissioners, etc." 2 Vols. Published at Albany by authority of the State of New York, 1825.

Note also paper in Vol. 2, Publications of the Buffalo Historical Society: "Origin and History of the Events that Led to the Construction of the Erie Canal," by George Geddes (son of James Geddes).

‡ For biographical notice, see Pennsylvania Magazine of History and Biography, Vol. X, 3, in the library of the Pennsylvania Historical Society, Philadelphia.

this condition of affairs could not long continue. As canal and railway projects grew apace, men whose education was obtained in the schools of experience were necessarily called to responsible positions, both on surveys and construction ; and it was owing to the possession of those admirable traits of early American character, energy, perseverance and close observation that led some of the young men, who began as axemen and rodmen to rise in the profession until they became distinguished engineers.

Notable instances of this fact are to be found in the careers of the following: John Edgar Thomson, an engineer of ability, and afterward President of the Pennsylvania Railroad, began as a chainman on the Portage Railroad in 1827.

John B. Jervis (born 1795), (whose memoir of American Engineering was published in the *Transactions* Am. Soc. C. E., for February, 1877), also began at the bottom of the ladder as a rodman on the Erie Canal in 1817, and rose to be Division Engineer of the Erie Canal in 1821, Chief Engineer Delaware and Hudson Canal Company, 1827, Chief Engineer Mohawk and Hudson Railroad, 1830, Chief Engineer Croton Aqueduct, 1836, and of the Boston Aqueduct 1845, and of the Hudson River Railroad in 1847.

Horatio Allen, began as an assistant to Mr. Jervis in 1828, and soon became Chief Engineer of the South Carolina Railroad, and was prominent as an engineer during a long and busy life which came to a close on the last day of 1889.

W. Milnor Roberts, began as a rodman on the Mauch Chunk Railroad, 1827; his Engineering Reminiscences are recorded in the *Transactions* Am. Soc. C. E., August, 1878.

Solomon W. Roberts, began as an assistant on the Allegheny Portage Railroad, 1831, and became a distinguished engineer.

W. Hasell Wilson, began as a chainman on the Pennsylvania Canal, 1827, and became Principal Assistant Engineer Reading Railroad, 1835, and Chief Engineer Gettysburg Railroad, 1838, and has held many positions of importance under the Pennsylvania Railroad.

Henry R. Campbell, began as a rodman on the Columbia Railroad, 1828, and became Chief Engineer Philadelphia, Germantown and Norristown Railroad, in 1832.

William J. McAlpine, who began as a rodman on the Delaware and Hudson Canal, in 1829, under John B. Jervis, and to whose ability Mr.

Jervis pays tribute in his memoir, attained a position of eminence as a hydraulic engineer. His death, since our last annual convention, is deeply mourned.*

Whatever may be the relation of engineering science to the history of the progress of other nations, of America it may be fairly said that the engineering profession typifies better than does any other the restless, progressive, practical spirit which has made this nation what it is.

In all parts of our country are found columns, and statues, museums and scholastic foundations which preserve the memory of our warriors and statesmen, our philanthropists and our philosophers. The political, military and literary annals of all nations have been sacredly guarded in all times, but the name of the architect who made the original design for the Cathedral at Milan, was lost in oblivion before that edifice was completed. If we may not be able to perpetuate the memories of the great pioneer engineers of America in granite, in marble or in bronze, let us at least make the endeavor to preserve a faithful record of their achievements, so that future generations of Americans shall not forget the names of Fulton, of Stevens, of Jervis, of Eads, of Ericsson, of the galaxy of brilliant men who have made it possible to develop the resources of our country, and whose works have carried the fame of American engineers to every part of the civilized world.

Evolution of Engineering Instruments.

The pace is mentioned once† in the Old Testament. The mile is also mentioned once in the English translation of the Bible,‡ and that is in

* Among numerous other civilian engineers, who have since filled positions of responsibility, are the following: William Strickland, Assistant Engineer, Pennsylvania Canal, 1826, and an author and architect of prominence; B. H. Latrobe, Chief Engineer Baltimore and Ohio Railroad; William R. Hopkins, Engineer Pennsylvania Canal, 1828; Moncure Robinson, under whose direction the surveys over the Allegheny Mountains were made for the Portage Railroad, in 1829; Sylvester Welch, Chief Engineer of the Allegheny Portage Railroad, in Pennsylvania, 1829; James Archibold, Chief Engineer Pennsylvania Coal Company, 1829; Russel T. Lord, General Superintendent and Engineer, Delaware and Hudson Railroad, 1830: Ashbel Welch, Engineer of the Raritan Canal, and Chief Engineer Belvidere Railroad, and President and Chief Engineer of the United Railroad and Canal Company of New Jersey, for many years; Samuel W. Mifflin, who began as an assistant on the Columbia Railroad, and after serving as Principal Assistant Engineer on Pennsylvania Works, became Chief Engineer, Huntington and Broad Top Railroad; Robert Pettit, J. Brinton Moore and others.

Charles B. Vignoles, who began his career as assistant to the State Engineer of South Carolina, where he was employed from 1817 to 1823, became Resident Engineer of the Liverpool and Manchester Railway from 1825 to 1827. To Vignoles has been assigned the credit of inventing the T-rail, in 1836, with a base, which is known in England as the Vignoles rail. (This is an error, as the first rail rolled with a base was designed by and manufactured under the direct supervision of Robert L. Stevens, in 1830.) Of all these men not one was fortunate enough to have a technical education.

† 2 Samuel, vi. 13: "And it was so that when they that bare the ark of the Lord had gone six paces, he sacrificed oxen and fatlings."

‡ Matthew v. 41: "And whosoever shall compel thee to go a mile, go with him twain."

the New Testament. The cubit is the general biblical measure, and that its length, without doubt, varied at different ages and in different places, is the belief of R. Flinders Petrie and other archæologists who have made a study of comparative metrology. The measuring rod, rule and line were used at a very early day. The quana, or measuring reed, 6 cubits long, corresponding to our 10 foot rod, is alluded to by Ezekiel, Chapter xl. and xli. The Prophet Isaiah (in the revised version) referring to the graven images, the worship of which was forbidden by the Jewish law, describes the manner in which these idols were marked out with the compasses and measured with the line.*

The scale which forms a part of the statue of the Chaldean architect at Tello, previously alluded to and now in the Louvre, is the oldest authentic measure known. It is thus described in a catalogue of the Paris Exposition of 1889:

"THE GRADUATED RULE.—It will be noticed that in general form it is like the *doubles dicinichres* which are used by our architects and engineers. Its length is about 27 centimeters or, more precisely, about 260 millimeters, if the pieces at the end, not marked off, are not taken into account. The unit of measure answers to the span or half cubit of the Chaldeans. This rule is also, as it would seem, a dividing instrument. One of its edges is divided into sixteen equal parts, which are then subdivided by twos into halves, thirds, quarters, fifths and sixths; then on the opposite edge, the sixths are divided into two parts, and into three parts, which produces twelfths and eighteenths—although the second edge is very much mutilated on the original statue, still it has been, from certain indications, possible to restore ninths and sixteenths. The restoration of the rule, in beam-tree wood, was made with the help of Tareb."

No other specimen can give a better proof of the advancement of exact science, at the time of Joudea, among the Chaldeans, the first to make a system of measurements.

It would appear that the wooden measuring rod was used before the line or chain. Before gunpowder was invented the spear was used by all savage tribes, and by the Egyptians and Romans, probably as a measure as well as a weapon. The names "rod" and "pole" both indicate their origin, and a wooden rod $16\frac{1}{2}$ feet in length, which is $\frac{1}{40}$ of a furlong† "is as long a rod as can be handled conveniently, even by a strong

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* "The smith maketh an axe and worketh in the coal and fashioneth it with hammers and worketh it with his strong arms."

"The carpenter stretcheth out a line, he marketh it out with a pencil; he sharpeneth it with planes, and he marketh it out with the compasses and shapeth it after the figure of a man." Isaiah, xliv.

† The $\frac{1}{50}$ of a furlong (660 feet) is 13 feet $2\frac{2}{3}$ inches, $\frac{1}{51}$ of a furlong is 10 feet $3\frac{3}{4}$ inches. "Scantling and boards in our day are seldom cut more than 16 feet long."

man." The rod of wood was also a favorite, doubtless from the fact that moisture did not cause it to vary seriously in length. Twisted hide or ropes of vegetable fibre, unless carefully prepared, were not suitable for measures of even approximate exactness. In a book printed in London, in 1562, entitled the "Most Profitable and Commendable Way of Surveying, etc., drawn up and collected by the Industrie of Valentine Leigh," the surveyor is informed that measurements may be made by a "rodde or a lyne," but Leigh prefers the latter, as being "speedier" and "most commodious." It is also here stated "your lyne being foure perches of lengthe, and at every perche ende a knot, should be well seared with hoate waxe and rosen," etc. Leigh speaks of the length of the "lyne" as 4 perches or 66 feet, as if it was an ordinary standard in his time. Scheventerus is quoted * as saying "A rope may contract one-sixteenth of its length when wet, and Wolfin directs that the little strands whereof the rope consists be twisted contrariwise, and the rope dipped in boiling hot oil and when dry drawn through melted wax."

In 1723, a book written by M. Bion, entitled the "Construction and Principal Uses of Mathematical Instruments," appeared in French, which was followed in 1725 by an English translation. The perusal of this book will demonstate the fact that excellent instruments for measuring lengths and angles were used by the French engineers one hundred and seventy-five years ago. On page 98 will be found the following description of the lines and rods used to measure length:

"Lines (see Fig. 12, Plate 27) ought to be of good pack thread or whip-cord, well twisted, and of a convenient thickness that they may not easily stretch. The toise (see Fig. 13, Plate 27) or fathom, is a round staff 6 foot long, divided into feet by little rings, or brass pins, the last foot being divided into 12 inches, likewise distinguished by little brass pins. There are toises that may be taken into two, three or four pieces, by means of ferils and brass screws at the end of each piece. There are also two brass or steel ferils put upon each end of the toise to preserve its length. In the year 1668, there was placed a new toise for a standard at the foot of the stairs of the Grand Chatelet, at Paris, for having recourse to in case of need."

The flag-rod, as we know it, is called a staff, and is thus described: "Staffs are made of hard wood, 2 or 3 foot long, cut peeked at one end, upon which are pointed caps of iron, to make them go easier in the ground. There are sometimes longer ones made, in order to be seen at a great distance."

Rules of bronze were used by the Egyptians, Greeks and Romans. In 1835, MM. Jomard and Walckenaer reported to the Academie des

* See Rees' Encyclopædia, 1810.

Inscriptions the description of a Roman foot-rule that was found near Caudabec. Upon it were marked the various measures in use in the years 253 to 268 of the Roman Empire.*

Metallic measures longer than a few feet would, of necessity, be unwieldy on account of their weight. Gold, silver, bronze and iron were worked in small pieces for chains for ornaments or use, at a very early age. Who can tell but that the neck chain of some ancient monarch or his queen may have been the unit of measure among his tribe or nation. To Edmund Gunter (1581–1626) we are indebted for the decimal division of the 66-foot chain into 100 links of 7.92 inches each.

Bion describes the French chains in use in 1723 as follows: "The chain (see Fig. 14, Plate 27) is composed of several pieces of thick iron or brass wire, bent at the ends, each of which is a foot long, and are joined together with little rings. Chains are commonly a perch, or else 4 or 5 toises, (24 or 30 feet) in length, distinguished by a great ring from toise to toise. These sort of chains are very commodious, because they will not entangle themselves, as those will that are made with little iron rings."

Sir George Schuckburg, in England, about 1780, had his chain made of steel, and corrected its length by allowing .05 inches for 13½ degrees of temperature. Rees' Encyclopædia states that the chain "ordinarily used for long distances is in lengths of 100 feet, each link 1 foot," and "in measuring towns a chain of 50 feet in length, consisting of 50 links, is the most commodious." A short chain is also described (for measuring small gardens or parcels). It was 1 rod long, consisting of 10 links 1.98 inches long.

In a very interesting discussion which appeared in the *Railway News*, about a year ago, the facts in regard to the origin of the 100-foot chain were put on record by several correspondents. It appears that although chains of 100 feet in length had been used previously, Colonel Stephen H. Long was probably the first person to dispense entirely with the 66-foot chain and to put the 100-foot chain in general use in an extensive survey on the Baltimore and Ohio Railroad, 1827–30. Long's "Railroad Manual," published 1829, contained explicit directions in regard to alignment, together with a table of curves for cords of 100 feet.

With the advancement of the textile industry it became possible to weave tape moderately free from contraction when wet, and the tape line came into use for measuring with approximate correctness. Linen tapes with ten or a dozen copper wire strands in the warp, were intro-

* Athenæum, September 26th, 1835.

duced perhaps twenty-five years ago. The steel tape with vernier for correcting length according to temperature is now used for accurate measurements.

Although the Odometer, or measuring wheel, was known to the Romans * before the Christian era, it does not appear to have been in-

* Vitruvius (Chap. XIV), thus describes a Roman Measuring Wheel: Let us now consider an invention by no means useless, and delivered to us by the ancients as ingenious, and by means of which, when on a journey by land or sea, one may ascertain the distance traveled. It is as follows: The wheels of the chariot must be 4 feet diameter; so that, marking a certain point thereon, whence it begins its revolution on the ground, when it has completed that revolution, it will have gone on the road over a space equal to 12½ feet. This being adjusted on the inner side of the nave of the wheel, let a drum-wheel be securely fixed, having one small tooth projecting beyond the face of its circumference; and in the body of the chariot let a small box be fastened, with a drum-wheel placed to revolve perpendicularly, and fastened to an axle. The latter wheel is to be equally divided on its edge, into four hundred teeth, corresponding with the teeth of the lower drum-wheel; besides the above, the upper drum-wheel has on its side one tooth projecting out before the others. Above, in another enclosure, is a third horizontal wheel toothed similarly, and so that the teeth correspond with that tooth which is fixed on the side of the second wheel. In the third wheel just described are as many holes as are equal to the number of miles in an usual day's journey. It does not, however, signify, if they be more or less. In all the holes let small balls be placed, and in the box or lining let a hole be made, having a channel, through which each ball may fall into the box of the chariot, and the brazen vessel placed under it. Thus, as the wheel proceeds, it acts on the first drum-wheel, the tooth of which, in every revolution, striking the tooth of the upper wheel, causes it to move on; so that when the lower wheel has revolved four hundred times, the upper wheel has revolved only once, and its tooth, which is on the side, will have acted on only one tooth of the horizontal wheel. Now, as in four hundred revolutions of the lower wheel, the upper wheel will only have turned round once, the length of the journey will be 5 000 feet, or 1 000 paces. Thus, by the dropping of the balls, and the noise they make, we know every mile passed over; and each day one may ascertain, by the number of the balls collected in the bottom, the number of miles in the day's journey. In navigation, with very little change in the machinery, the same thing may be done. An axis is fixed across the vessel, whose ends project beyond the sides, to which are attached wheels 4 feet diameter, with paddles to them touching the water. That part of the axis within the vessel has a wheel with a single tooth standing out beyond its face; at which place a box is fixed with a wheel inside it having four hundred teeth, equal and correspondent to the tooth of the first wheel fixed on the axis. On the side of this, also, projecting from its face, is another tooth. Above, in another box, is enclosed another horizontal wheel, also toothed, to correspond with the tooth that is fastened to the side of the vertical wheel, and which, in every revolution, working in the teeth of the horizontal wheel, and striking one each time, causes it to turn round. In this horizontal wheel holes are made, wherein the round balls are placed; and in the box of the wheel is a hole with a channel to it, through which the ball descending without obstruction, falls into the brazen vase, and makes it ring. Thus, when the vessel is on its way, whether impelled by oars or by the wind, the paddles of the wheels, driving back the water which comes against them with violence, cause the wheels to revolve, whereby the axle is also turned round, and consequently with it the drum-wheel, whose tooth, in every revolution acts on the tooth in the second wheel, and produces measured revolutions thereof. Wherefore, when the wheels are carried round by the paddles four hundred times, the horizontal wheel will only have made one revolution by the striking of that tooth on the side of the vertical wheel, and thus, in the turning caused by the horizontal wheel every time it brings a ball to the hole it falls through the channel. In this way, by sound and number, the number of miles navigated will be ascertained. It appears to me, that I have completed the description in such a manner that it will be easy to comprehend the structure of the machine, which will afford both utility and amusement in times of peace and safety.

troduced into England or France before the 18th century. Bion describes a wheel with clock-work and counter (see Fig. 15, Plate 27).

The mile* (Roman mille passus), derived from mille, a thousand, strangely enough in our day has lost all connection with the decimal system. In discussing the origin of the English mile, Petrie states that "the statute mile and furlong were probably independent of each other originally," and that "the earliest mile near the statute mile was one of 5 000 feet, defined as 7½ furlongs, 3 perches and 2 palms." It is described by De Morgan in article "League," in "Penny Encyclopædia." The furlong is probably the older measure, and the 280 feet were added between 1350 and 1470 to the 5 000 to make 1 mile equal 8 furlongs. The origin of the English mile, the acre, and the 66-foot chain has been discussed by other eminent antiquarians,† who find that the Roman mile, the German mile, the Irish mile and the English mile have varied in length in different centuries.

The acre, as established by Edward I was 160 square perches, 16 long and 10 wide. A piece of ground laid off in this shape was easily divided into halves (8 x 10), quarters (8 x 5, or 4 x 10, or roods), eighths (2 x 10, or 4 x 5), sixteenths (1 x 10, 2 x 5), or thirty-seconds (1 x 5) and into fifths, (2 x 16) or tenths, (1 x 16, or 2 x 8).

As hydraulic engineering was practiced in the earliest times, the level must have been used centuries ago. Crude in form at first it was gradually improved until it reached the perfection of to-day.‡

* See "Old English Mile," by W. Flinders Petrie, Proceedings Royal Society, Edinburgh, Vol. XII, No. 115.

† See "Penny Cyclopædia." I have seen it stated, but I cannot find the reference, that the perch was originally three times the height of a man.

‡ Vitruvius thus describes the chorobates, a kind of level used previous to the Christian era: The chorobates is a rod about 20 feet in length, having two legs at its extremities of equal length and dimensions, and fastened to the ends of the rod at right angles with it. Between the rod and the legs are cross pieces fastened with tenons, whereon vertical lines are correctly marked, through which corresponding plumb lines hang down from the rod. When the rod is set, these will coincide with the lines marked, and show that the instrument stands level. But if the wind obstructs the operation, and the lines are put in motion, so that one cannot judge them, let a channel be cut on the top of the rod, 5 feet long, 1 inch wide, and half an inch high, and let water be poured into it; if the water touch each extremity of the channel equally, it is known to be level. When the chorobates is thus adjusted level, the declivity may be ascertained. Perhaps some one who may have read the works of Archimedes will say that a true level cannot be obtained by means of water, because that author says that water is not a level, but takes the form of a spheriod, whose center is the same as that of the earth. Whether the water have a plane of spheroidal surface, the two ends of the channel on the rod, right and left, when the rod is level, will, nevertheless, sustain an equal height of water. If it be inclined toward one side, that end which is highest will not suffer the water to reach to the edge of the channel of the rule. Hence, it follows that though water poured in may have a swelling and curve in the middle, yet its extremities to the right and left will be level. The figure of the chorobates will be given at the end of the book. If there be much fall, the water will be easily conducted, but if there be intervals of uneven ground, use must be made of substructions.—Vitruvius, Book VIII, Chap. 6, pages 195, 196.

Bion describes* several types of water levels, plumb levels, air levels and telescope levels, which it is only necessary to illustrate (see Figs. 16–22, Plate 27), as the method of their construction and use is quite clear. In describing the latter he states that: "At the end of the tube of the telescope enters the little tube carrying the eye-glass and a human hair, horizontally placed, in the focus of the object glass."

Among the earliest instruments for measuring angles was the gnomon with which the Babylonians were familiar, and from whom Herodotus states (II, 109), "the Greeks learned the use of it, together with the pole." The comparison of the perpendicular height of the gnomon with the length of its meridian shadow projected on a horizontal plane on the days of its summer and winter solstices, afforded the early astronomers an opportunity to calculate the difference of the sun's meridian altitudes on those days.

Although the circle is a figure which has been found in nature from time immemorial, Isaiah xliv, 13, contains the only reference to a pair of compasses to be found in the Bible. The Hebrew word which was translated "compass" in the old version, is *mehugah*, from *hug*, a circle, *mehug*, something to make a circle. In the revised version the phrase is translated, "he marketh it out with the compasses." There can, therefore, be little doubt that an instrument similar to what is now known as the "compasses" or dividers was used by the Hebrew mechanics. So that, even if we accept the theory of a deutero Isaiah, this instrument can certainly claim the respectable antiquity of the 6th century B. C.

The circle was associated with the measurement of time and for astronomical observations many centuries before the Christian era. The sun dial† of Ahaz is thus mentioned, Isaiah xxxviii, 8: "Behold I will bring the shadow of the degrees which is gone down in the sun dial of Ahaz, 10 degrees backward. So the sun returned 10 degrees by which degrees it was gone down."

The division of the circle into 360 degrees is usually ascribed to the Egyptians,‡ probably from the circle of the sun's annual course, or ac-

* See pages 134, 135, 136.

† By early Biblical translators it was supposed that this dial might have been a simple obelisk whose shadow fell upon the steps of the palace of Ahaz, and that each step was called a degree. More recent writers believe, however, that these degrees were marked on a plane of stone or metal.

‡ The division of the circle into 360 degrees has not been the custom from time immemorial, as the papers of Sayce and Bosanquet, describing a planisphere found in the palace of Sennacherib (705–681 B. C.), now in the British Museum, in the Monthly Notes of the Royal Astronomical Society for 1880, Vol. II, No. 3, amply proved.

cording to their number of days in the year, allotting a degree to each day. It is a convenient number, too, admitting of a great many aliquot parts, 2, 3, 4, 5, 6, 8, 9, etc. The sexagesimal subdivision, however, has often been condemned as improper by many eminent mathematicians, such as Stevinus, Oughtred (1574–1660), Wallis (1616–1703), Briggs (1556–1630), and Newton, all of whom advised a decimal division instead of it, or else that of centesms, as the degree into one hundred parts and each of these into one hundred parts, and so on. Sir Isaac Newton (1642–1727) made several large tables of sines according to the plan of dividing each degree into 100 minutes of 100 seconds each. Some French mathematicians divided the quadrant into 100 degrees, and those into decimals of degrees. William Crabtree, Gascoigne and Jeremiah Horrocks* (1619–1641) projected tables with complete decimal divisions, the whole arc of the circle being divided into 100 000 000 parts.† Dr. Charles Hutton, in the early part of this century, published extensive tables giving real lengths of arcs of various decimal degrees in terms of the radius. ‡

Comenius,‖ who published "Orbis Sensualium Pictus," translated into English by Charles Hoole in 1658, describes the instruments (see Fig. 23) used by the geometrician (C. V.), as follows: "A geometrician measureth the height of a tower, 1....2, or the distance of places, 3....4, either with a quadrant, 5, or a Jacob's staff, 6. He marketh out the figures of things with lines, 7, angles, 8, and circles, 9, by a rule 10, a square, 11, and a pair of compasses, 12. Out of these arise an oval, 13, a triangle, 14, a quadrangle, 15, and other figures."

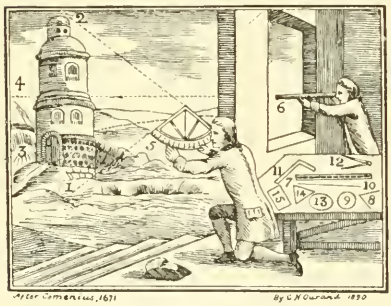

FIG. 23.

Among the simpler instruments for surveying is the cross, thus described by Bion (Math. Insts., Chap. I):

"The surveying cross (see Fig. 24, Plate 27) is a brass circle of good thickness, and 4, 5, or 6 inches in diameter. It is divided into four equal

* Horrocks observed the first transit of Venus that was carefully observed 24th November, O. S. 1639. That predicted by Kepler in 1631 being invisible in Europe.

† Philos. Trans., Vol. 27, page 230.

‡ Philosophical and Mathematical Dictionary, by Charles Hutton, LL.D., London, 1815. Vol. I, page 399.

‖ John Amos Comenius, Moravian Friar and Schoolmaster, b. 1592, d. 1671. Author of the first illustrated "Nomenclature of the Chief Things that are in the World."

parts by two lines cutting one another at right angles in the center. At the four ends of these lines, and in the middle of the limb, there are fixed four strong sights, well riveted in square holes, and very perpendicularly slit over the aforesaid lines, having holes below each slit for better discovery of distant objects; the circle is hollowed to render it more light."*

This instrument was moved along a line connecting two angles of the polygon (not contiguous) until the other angles came in view through the sights set at right angles to this base line. The distances along the base line, and from it at right angles to the other angles were carefully measured, plotted, and the angles determined from the plot.

Neither the Romans nor the Greeks appear to have had any knowledge of the loadstone or magnet previous to the Christian era, although the Chinese appear to have used the magnetic needle over two thousand years before. Vitruvius, who wrote about B.C. 25, in describing the method of laying out the streets of a city, north and south, states that the gnomon † was used.

The engineer is indebted to the navigator for the magnetic compass and to the astronomer for the theodolite and transit. The accurate division of the circle into degrees and minutes was, without doubt, first

* The description continues: "Underneath and at the center of the instrument there ought to be screwed on a feril, serving to sustain the cross upon its staff of 4 or 5 feet long, according to the height of the observer's eye. This staff must be finished with an iron point to go into the ground the better. All the exactness of this instrument consists in having its sights well slit at right angles, which may be known by looking at an object through two sights, and another object through two other sights; then the cross will be exactly turned upon its staff, and you must look at the same object through the opposite sights; if they are very exactly in the direction of the slits, it is a sign the instrument is very just. To avoid breaking or damaging the cross, the staff must first be put in the ground, and when it is well fixed the cross must be screwed upon it. These kind of crosses sometimes are made with eight sights, in the same manner as the aforesaid one and serve to take angles of 45 degrees; as, also, for gardeners to plant rows of trees by."

† To find and lay down their situation we proceed as follows: Let a marble slab be fixed level in the center of the space enclosed by the walls, or let the ground be smoothed or leveled, so that the slab may not be necessary. In the center of this plane, for the purpose of making the shadow correctly, a brazen gnomon must be erected. The Greeks call this gnomon. The shadow cast by the gnomon is to be marked about the fifth ante-meridianal hour, and the extreme point of the same accurately determined. From the central point of the space whereon the gnomon stands, as a center, with a distance equal to the length of the shadow just observed describe a circle. After the sun has passed the meridian, watch the shadow which the gnomon continues to cast till the moment when its extremity again touches the circle which has been described. From the two points thus obtained in the circumference of the circle describe two arcs intersecting each other, and through their intersection and the center of the circle first described draw a line to its extremity; this line will indicate the north and south points.—Vitruvius I, 6.

practiced by astronomers* in the construction of instruments for the observation of the heavenly bodies.

Different methods for dividing the circles for instruments into degrees and their subdivisions by hand were successfully practiced by Tycho Brahe, Hevelius, Dr. Hooke, Ole Roemer, John Bird, James Bird, Jesse Ramsden and Mr. Troughton, without the aid of a dividing engine.

Bion describes the compass (see Fig. 25, Plate 27) used in 1723, as follows (page 117): "This instrument is made of brass, ivory, wood, or other solid matter, from 2 to 6 inches in diameter, at the bottom of which is described a card whose circumference is divided into 360 degrees. In the center of this card is fixed a well-pointed brass or steel pivot, whose use is to carry the touched needle placed upon it, in equilibrio, so that it may freely turn. One of the ends of the needle always turns towards the north part of the world, but not exactly,† it declining therefrom, and the other towards the south.

"Needles ‡ are made of pieces of steel, the length of the diameter of the box, having little brass caps soldered to their middle, hollowed into a conical figure so that the needle being put upon the pivot, may move very freely upon it, and not fall off; they are nicely filed into different figures, those which are large being like a dart, and small ones have rings towards one end, for knowing that end which respects the north, as may be seen in the little figures nigh the compass."

That the Chaldeans understood the uses of the plane table there can be no doubt. The Chaldean architect previously mentioned, holds on his lap a tablet,‖ "which takes the place precisely of the plane tables of our architects, and must have been made of sun-dried clay, like the smaller tablets which were used for Chaldean writing. Like the latter, the lines of the plan are deeply cut. The tablet could afterward be baked like a brick, and the design would thus be preserved for an indefinite length of time."

The plane table (see Fig. 26, Plate 27) is described by Bion§ together with its uses in connection with the circumferenter (see Fig. 27, Plate 27), which he also describes as follows: "This instrument consists of a brass index and circle, all of a piece; the index is commonly made about 14 inches long, 1½ inches broad, and of a convenient thickness.

* Claudius Ptolemy in his "Almagest," written 145 A.D., describes an astrolabe or circular instrument for making celestial observations, which consisted of heavy circle of metal, arranged that when it was suspended, the divisions which we now call 0 and 180 would come to rest in the same horizontal plane. A diametrical bar suspended in the center of the circle and turning on a pin, was furnished with disks containing slits, through which any heavenly body could be seen and its altitude determined in degrees or parts thereof.

† According to observations made in October, in the year 1715, in the Royal Observatory, the needle declined 2 degrees 5 minutes westwardly.

‡ Bion thus describes the manner of magnetizing the needle: "To touch a needle well, having first got a good stone, begin your touch near the middle of the needle, and pressing it pretty hard upon the pole of the stone, draw it slowly along to the end of the needle, and lifting your hand a good distance from the stone, while you put the needle forward again, begin a second touch in the same manner as after that a third, which is enough, only take care not to rub the needle to and fro on the stone, whereby the backward rubs take away that virtue the forward ones gave; but lift it out of the sphere of the stone's virtue when you carry it forward again to begin a new touch."

‖ See Catalogue Paris Exposition, 1889. § Page 128.

The diameter of the aforenamed circle is about 7 inches. On this circle is made a card, whose meridian line answers to the middle of the breadth of the index; that card is divided into 360 degrees. There is a brass ring soldered on the circumference of the circle, on which screws another ring with a flat glass in it; so that they make a kind of box to contain the needle suspended upon the pivot placed in the center of the circle."

I have been unable to ascertain where or by what nation or when the theodolite * was invented. It was certainly the outgrowth of the quadrant or sextant. It is interesting to note that the earlier theodolites were not furnished with graduated metallic circles, as such work, which was of necessity done by hand before the dividing engine was introduced, was very costly. The bearings of each survey were marked with a pen upon a circle of pasteboard, the names or numbers of each station being written upon the radial lines, upon which the diametrical bar rested when the station was sighted.

The surveyor retained these cards which was his record of the survey. This method, at least, had the merit of eliminating one possibility of error—that of a mistake in reading the instrument.

The Theodolite of 1723 (see Fig. 28, Plate 27) is described by Bion page 106.†

It was not customary to measure the lengths or to take the bearings of the boundary lines at that time, according to the present practice. The instrument was set up at some central point on the tract to be surveyed, and the distances to the boundary stones were all measured from the instrument, the angles being determined by lines drawn on the

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* Comenius makes no mention of it.

† Construction and Use of the Theodolite. This instrument is made of wood, brass or any other solid matter, commonly circular, and about 1 foot in diameter. In the center of this instrument is set upright a little brass cylinder, or pivot about which an index turns, furnished with two sights or a telescope, having a right line, called the fiducial line, exactly answering to the center of the aforesaid little cylinder, whose top ought to be cut into a screw for receiving a nut, to fasten the index upon which is fixed a small compass for finding the meridian line.

The limb of the theodolite is a circle of such a thickness as to contain about six round pieces of pasteboard within it (of which we are going to speak) and of such a breadth as to receive the divisions of 360 degrees, and sometimes of every fifth minute. There are several round pieces of pasteboard of the bigness of the theodolite, pierced through the middle with a round hole, exactly to fit the pivot; so that the pivot may be put through each of the aforesaid holes in the pieces of pasteboard, and the upper pasteboard may have the index moving upon it. This upper pasteboard may be fixed at pleasure, by means of a little point fastened to the limb of the instrument, and entering a little way into the pasteboard. There is commonly drawn with ink, upon each of these pasteboards, a radius or semi-diameter, serving for a station-line.

card when the axis of the instrument was properly sighted on the point. The manner of doing this is also described by Bion.*

With the invention of the English dividing engine, which was perfected by Jesse Ramsden, and for which Maskeline, the Astronomer Royal of England, was authorized to pay a bounty of £615 in 1776, upon condition that sextants should be graduated for six shillings, the cost of graduating circles and straight scales was reduced to such a figure that it was practicable to furnish all good instruments with graduated metallic circles. The great theodolite, belonging to the Board of Ordnance, and used for measuring the principal angles of the British Trignometrical Survey, in 1785, was graduated on Ramsden's machine. It had a horizontal circle of 3 feet in diameter, and two telescopes of 36 inches focal length.

The surveying and engineering instruments used in America during the last century were obtained generally from England and France. In the report of Holland and Rittenhouse, Commissioners to determine the boundary between New York and Pennsylvania, dated December 14th, 1774, they state that in determining the initial point of the 43d degree of north latitude, they "made several observations with a good Hadley's quadrant," they also used "an excellent astronomical sector of 6 feet radius, made by Mr. Bird (of London), with which we made the observations, when the several stars were on our meridian." The instruments purchased for the West Point Academy came, mainly, from England, where Dollard had made a great reputation as an instrument maker. Hassler, who brought a number of instruments with him from Switzerland, in 1805, was sent to England in 1811 to procure instruments for the Coast Survey.

With General Barnard's advent at West Point, French instruments came again into favor.

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* Uses of the Theodolite, page 107: To take the map of the country by this instrument, chuse two high places, for example, the Observatery and the Salt-Petre House, from whence the country nigh Paris, a map of which is to be made, may be seen; then mark around the center of the upper pasteboard the name of the place chosen for the first station, and having fixed it by means of the point on the limb of the theodolite, put the index upon it, which sufficiently screw down by means of the nut and screw. Now having placed the theodolite upon its foot, planted at the Observatory, and giving it a situation nearly horizontal, so that it may remain steady while the index is moving, observe through the sites the steeple of the Salt-Petre House, and along the fiducial line of the index from the center draw the station line. Then turn the index, and observe some remarkable object through the sights, as the steeple of Vaugirard, toward which a line must be drawn upon the pasteboard, from the center along the fiducial line of the index, and along this line write the name of the place viewed through the sight.

September 11th, 1789, Andrew Ellicott, one the most prominent surveyors of the time, writes to the Executive Council of New York: "In executing the survey to be made on Lake Erie, I shall stand in need of two surveying instruments and a small quadrant, the property of this commonwealth." In reply, the Council "Resolved, That the request of Mr. Ellicott be complied with, and that David Rittenhouse be directed to furnish him said instruments, taking a receipt to return them when required."

In 1794, when it was desired to survey a large tract of land, near the village of Geneva, N. Y., afterward known as the Pulteney Estate, Surveyor-General De Witt reported "that there were only two transits in the country, one owned by Andrew Ellicott, the other by Dr. Rittenhouse, neither of them available."* The surveys of the District of Columbia, under the direction of Andrew Ellicott, were made with great care. Describing the methods adopted, in a letter to Robert Patterson, April 2d, 1795, Ellicott says: "These lines were traced with a transit and equal altitude instrument, which I constructed and executed in 1789. This instrument I used in running the principal avenues† in the City of Washington."

A surveyor's compass belonging to General Washington and now preserved in the collection of the National Museum, bears the name of David Rittenhouse, who had an establishment in Philadelphia in 1767.

William J. Young began the construction of engineering instruments in Philadelphia as early as 1820 and carried on the business for fifty years in that city. A transit instrument invented by him in 1831 was regarded as a great improvement over the English theodolite, which was not in favor among the early American engineers, on account of its being slow and inconvenient. I find it recorded that this instrument was used "in setting the first peg that was driven for the extension of the Baltimore and Ohio Railroad, west of Harper's Ferry."

Messrs. W. & L. E. Gurley, of Troy, N. Y., have furnished me with

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* Report of Regent's Boundary Com., Mayor H. W. Clark, Albany, 1886.

† In another report Ellicott states: "These lines were measured with a chain, which was examined and corrected daily, and plumbed wherever the ground was uneven and traced with a transit and equal altitude instrument, which I constructed and used in running the western boundary of the State of New York" "This instrument was similar to that described by M. Le Monnier in his preface to Histoire Celeste, except in being accommodated to a firm portable triangular frame. The transit and equal altitude instrument is of all others the most perfect and the best calculated for running straight lines, and when the different verifications are carefully attended to, may be considered as absolutely perfect."

the following information in regard to American instruments, under date of May 23d, 1890:

"We believe the first maker of surveyor's instruments in America was David Rittenhouse of Pennsylvania, who invented a movable circle with vernier, by which in the ordinary surveying compass (or circumferenter as the English still term it), the declination of the needle can be set off upon the compass at once, and all error arising from the secular variation of the needle be avoided. This style of compass was for many years known as the Rittenhouse compass."

"In 1831, William J. Young of Philadelphia, devised an instrument like the English theodolite, except that the telescope was made like that of the astronomical transit, to make a complete revolution and thus enable an engineer to run lines in diametrically opposite directions without reference to the divided limb. This was the origin of the American transit which has been improved until it is the favorite of all engineers entirely superseding the employment of the English theodolite. In 1836, William A. Burt of Michigan, made a most ingenious astronomical and surveying instrument termed the solar compass (page 100 of Manual), and this has been largely used in our own country as well as abroad. We commenced to make instruments about forty-five years ago, have made many improvements, some of which have been patented and are described in our Manual."

The introduction of aluminum has made it possible to create a marked reduction in the weight of all engineering instruments, thus adding to the comfort and convenience of the engineer.

The testing machine* has been of the greatest assistance in the scientific investigation of the modern engineer. One of the first machines for making physical tests was designed and built by the late Major Wade for the United States Government, in 1855 and 1856, and was used in making experiments on the cast-iron intended for the ordnance service. A little later this machine was remodeled and improved by Captain Rodman. A few years later George W. Plympton, Am. Soc. C. E., made numerous experiments on some full sized rods designed to be used in bridges, with a testing machine of unusual dimensions which was designed and constructed by J. W. Murphy of Philadelphia.

Mechanical Engineering.

The practice of mechanical engineering began with the use of the lever, the inclined plane, the roller, and then the pulley. The prehistoric hunters returning from the chase with the game suspended upon a pole, nearer to the stronger man, were led by instinct to apply the principles that govern the use of the lever. With the introduction of

* For discussion upon "Testing Machines, their History and Use," by Arthur V. Abbott, see Van Nostrand's Magazine, March, 1884.

the rolling log, the sledge with rollers under it, and finally the wheel—man's sphere of usefulness was greatly enlarged. By the cumbersome sledge and the crude cart animal power was utilized and the patient ox, or buffalo, was called to work, often harnessed side by side with the human draft animal. Man continued his conquest over the animal kingdom and the fleet-footed horse was tamed first to bear his human burden and then to aid his captor in warfare. The sledge and cart were not adapted to his rapid pace and the Hittite or Babylonian wheelwright was called upon to combine bronze or iron and wood in the wheels for the war chariot for his monarch. After learning to make a hub and felloe and how to secure the spokes to both, the ancient mechanic, who had already applied animal power to tread-mills, to capstans for driving boats, and other uses, began to take the steps that

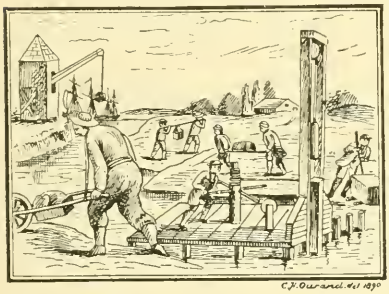

Fig. 29.

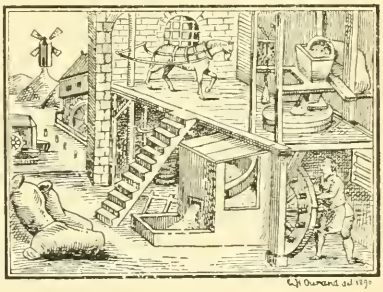

Fig. 30.

were to ameliorate the condition of the human and animal race, steps that were to break the fetters from the galley slave and to remove the galling yoke from the neck of man's patient friends of the animal kingdom. Then began the battle with the elements to make them man's slaves. The water that had been his barrier in war, and a supply of which was necessary for his existence, was put in bonds by ditch and dam and driven through wheels until a portion of the stream, at least, was made to rise above its source. The winds that had blown down his tents and damaged his crops was made to drive the wheel to grind his corn.

Comenius, in 1658, thus illustrates* (See Fig. 29) the "engines" used for lifting and moving weights in the early part of the 17th century, and thus describes them: "One can carry as much by thrusting a wheel-

* See No. LXVIII, page 84.

barrow (3) before him (having an harness (4) hanged on his neck), as two can carry on a cole-staff (1) or hand barrow (2). But he can do more that rolleth a weight laid upon rollers (6) with a leaver (5). A wind-beam (7) is a post, which is turned by going about it. A crane (8) hath a hollow-wheel, in which one walking draweth weights out of a ship, or letteth them down into a ship. A rammer (9) is used to fasten piles (10), it is lifted up with a rope drawn by pullies (11) or with bands, if it have handles (12)."

The horse-mill, water-mill and wind-mill (See Fig. 30) of that era, are also graphically depicted thus:* "In a mill (1) a stone (2) runneth upon a stone (3). A wheel (4) turning them about and grindeth corn poured in by a hopper (5) and parteth the bran (6) falling into the trough (7) from the meal flipping through a bolter (8). Such a mill was first a hand-mill (9), then a horse-mill (10), then a water-mill (11), and a ship-mill (12), and at last a windmill (13). The turning lathe (See Fig. 31), he thus describe: The turner sitting over the treddle, turneth with a throw upon a turner's bench, bowls, tops, puppets and such like turner's work."

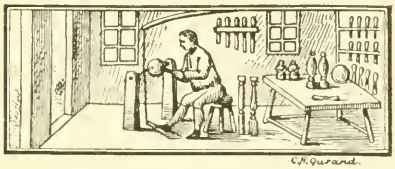

Fig. 31.

Man has been described as a fire-making animal. The archæologist delving among the remains of the neolithic and paleolithic epochs hails every object indicating the presence of non-volcanic and non-electric fire as a certain evidence of man's existence upon the earth at that period. Wind and water, former enemies, having been subdued, he continued his conquest over fire, and as the principles of thermodynamics, the vacuum, and expansive properties of the air became understood by Galileo, Torricelli, Guericke, Huyghens, Papin, Savery, Newcomen and Smeaton, the fire-engine was invented and put to work to drain the mines.

Who can tell when or where the steam rising from the earthern vessel helping man bend the wood for his chariot wheels, or what not, first impressed him with its power. There were the fire and the water and the wheel; who was to devise the machine by which the steam should be made to turn the wheel? The history of the progress from the Egyptian æolipile to the triple expansion steam-engine, together with the philosophy of its invention has been amply recorded by a distinguished Member† of this Society, so that there is no necessity, even if there were time, to allude to Newcomen, Hornblower, Watt, Trevithick and Oliver Evans, and the other pioneers who during the last century struggled with the elementary problems of steam engineering. In the National

* See LI, page 65. See LXXIV, page 91.
† Dr. Charles B. Thurston, History of the Steam Engine, etc., etc.

Museum we have a portion of the original cylinder of the first stationary engine put to work on the Western Continent by Hornblower, in 1753, at Belleville, near Newark, N. J.

Here was established the first machine shop in America, and here, about 1798, the pumping engine for the Fairmount Water Works, at Philadelphia, was built. Some idea of the crude appliances of that era can be gathered from the fact that it took between two and three months to bore the cylinder of that engine. It would be, indeed, interesting to trace the history of the invention of the lathe, the drill, the planing machine,* and other tools which have made the present perfection in machine work possible.

In 1800, the Manhattan Company imported an engine from England to supply New York with water from the Collect Pond, near the present location of the Tombs prison. The company was incorporated by the Legislature of New York, and the act of incorporation † was drawn by Aaron Burr. The Englishmen and Scotchmen who helped to build the engine remained in America, and also built machine shops. McQueen, a Scotchman, established a shop on the east side of Broadway, in Duane street, about 1806. He helped make the engine for the steamboat "Phœnix." The steamboat "Clermont" (1807), was built at Corlears Hook, near the foot of Houston street, New York City. Fulton established a shop in Jersey City, near the present location of the Pennsylvania Railroad Depot, about 1809, and imported a number of English mechanics from Birmingham. The first machine-shops in Philadelphia were established about 1809–10, Oliver Evans's being among the first. In 1822, West Point foundry shops were established at the foot of Beach street, New York, and here much steamboat work was done.

The history of the locomotive has been authentically placed upon record by another distinguished member of this society, whose catechism of the locomotive will be the text-book for those interested in that study for years to come. It is only necessary to repeat the names of Cugnot, Murdoch, who was condemned by Watt for his experiments with high pressure steam, Trevithick, who constructed the first locomotive to help man, Hackworth, Ericsson, George and Robert Stephenson, Jarvis and

* I am informed by Mr. F. E. Sickles that the first planing machine in America was imported in 1830, for a machine shop located at the Allaire Works at the head of Cherry street, New York City.

† At the end it briefly mentioned that their "surplus capital could be used for other purposes," and upon the faith of that the Manhattan Company established the Manhattan Bank.

Dripps, who applied the principles of the bogie or truck to the front of the locomotive, Robert L. Stevens, John Stevens, who constructed the first steam carriage with a multi-tubular boiler, Allen, Baldwin, whose mechanical mind evolved and improved the locomotive from the beginning, and Norris, whose locomotive was the first (1832) to climb a heavy grade, to recall what each of these pioneers accomplished when we measure the progress of locomotive invention. Does it seem possible that the man who handled the throttle on the first locomotive put on a railroad in the Western Hemisphere could have been alive less than a year ago?

In looking into the careers of those early mechanical engineers, who have obtained fame and fortune, we must not consider that they succeeded by intuition or inspiration, nor can we hope to find that they made no mistakes. Watt censured his foreman, Murdoch, for experimenting with high pressure steam, which he believed could only be made useful by some miraculous dispensation. George Stephenson, the best mechanic of his time, spent many weary days and sleepless nights at one period of his life in an attempt to make a perpetual motion machine; yet whose names are dearer to the hearts of those who appreciate what the steam-engine and locomotive have accomplished for humanity, than James Watt or Robert Stephenson? Ericsson spent his last days in planning an imperfect solar engine; and some of our most distinguished physicists have devoted years to unsuccessful attempts to navigate the air. None have as yet achieved success, but who can tell what moment the data which they have collected shall be found to be of the utmost practical importance?

Bridge Engineering.

Upon the result of careful and systematic investigations into the strength of various materials and their properties, has been founded the science of bridge engineering. Galileo (about 1600 A. D.) expounded a theory of the strength of materials. Leibnitz (about 1675) originated the idea of the force of extension of a fiber being proportional to its distance from the lower side of a bent beam. As early as 1676 Hooke enunciated his celebrated law "within the limits of elasticity the strain produced by a stress of any one kind is proportional to the stress producing it." Venturoli advanced theories in regard to the strength of materials during the last century. In 1817, Professor W.

H. Barlow published an elaborate "Essay on the Strength and Stress of Timber," which was discussed by Dr. Dalton and others.*

Professor Eaton Hodgkinson, to whom the profession is indebted for a series of elaborate experiments extending over many years, showed "both theoretically and experimentally the true method of determining in the section of fracture the exact position of the neutral line, and of calculating the strength of the beam."† To Daniel Bernoulli the engineering profession is indebted for founding the system of hydrodynamics and hydraulics.‡

The causes of the failure of the chain bridge at Broughton, Manchester, which gave way in 1827, because of the vibration caused by a troop of soldiers who marched across it, keeping step to a drum and fife, is discussed in Leslie's "Geometry of Curved Lines," in which it is stated that the properties of the catenary curve were first discovered by Bernoulli. In 1828, he presented papers "On the Chain Bridge at Broughton," and "On the Forms of the Catenary in Suspension Bridges." The paper upon the "Theoretical and Experimental Researches to Ascertain the Strength and Best Forms of Iron Beams," which appeared in 1830, formed the basis for the designing of the celebrated "Hodgkinson's Beams," being the strongest beams that can be made from cast-iron, the quantity of material, length and depth of beam being considered. In the "Third Report of the British Association for the Advancement of Science," 1833, are two reports to which he contributed—"On the Effect of Impact on Beams," and "On the Direct Tensile Strength of Cast-Iron."

Thomas Tredgold (1827), made many experiments on the strength of cast-iron and other materials, which were published and used as the basis of calculation at the beginning of the railway era in England. Hodgkinson and Tredgold were followed by other distinguished investigators, among whom were Canon Mosely,§ Dr. Whewell,‖ Dr. Robinson, Colonel Sir Henry James, Capt. Galton, Professor Willis, Dr. Stokes, and Mr. H. Stokes, and others in England and America.

* Barlow, in 1832, prepared an exhaustive report "On the present state of knowledge respecting the Strength of Materials," which he published in the 3d Volume Reports British Ass. Adv. of Science.

† See Memoir of Eaton Hodgkinson, by Robert Rawson, Report of the Smithsonian Institution, 1868; also in a paper presented to the Literary and Philosophical Society of Manchester, England, in 1822, "On the Transverse Strain and Strength of Materials."

‡ See D'Aubisson's "Hydraulics."

§ See "Engineering and Architecture."

‖ See "Analytical Statics."

Bridges of Wood and Stone.—"A bridge," said Michael Angelo, "ought to be built as though it were intended to be a cathedral, with the same care and of the same materials."* Timber bridges consisting of hewed logs, supported by piers of piling or of stone, were erected in the earliest times in all countries where timber was plenty. Cæsar's bridge (see Figs. 32 *a* and *b*) was of this character.†

Remains of a wooden stringer bridge built by the Greeks, during the Peloponnesian War, B. C. 425, are to be found in the Island of

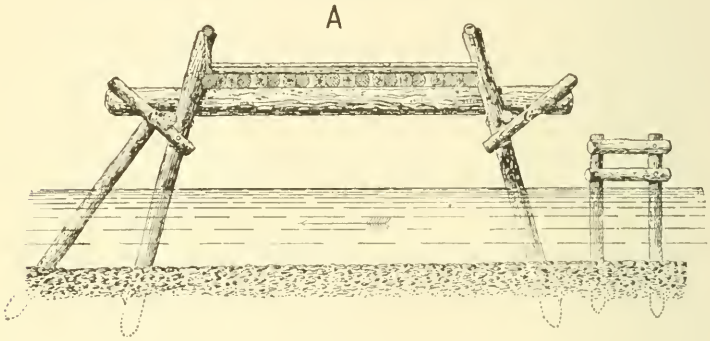

Fig. 32*a*.

* Of the three hundred and fifty-nine ancient bridges of Venice not one was permitted to fall into decay.

† It is thus described: "He devised this plan of a bridge. He joined together at the distance of 2 feet two piles, each 1½ foot thick, sharpened a little at the lower end, and proportioned in length to the depth of the river. After he had by means of engines sunk these into the river, and fixed them at the bottom, and then driven them with rammers, not quite perpendicularly, like a stake, but bending forward and sloping so as to incline in the direction of the current of the river, he also placed two other piles opposite to these at the distance of 40 feet lower down, fastened together in the same manuer, but directed against the force and current of the river.

Both these, moreover, were kept firmly apart by beams two feet thick (the space which the binding of the piles occupies), laid in at their extremities, between two braces on each side; and in consequence of these being in different directions and fastened on sides the one opposite the other, so great was the strength of the work, and such the arrangement of the materials, that in proportion as the greater body of water dashed against the bridge, so much the closer were its parts held fast together. These beams were bound together by timber laid over them in the direction of the length of the bridge, and were covered over with laths and hurdles; and in addition to this, piles were driven into the river obliquely at the lower side of the bridge, and these serving as buttresses, and being connected with every portion of the work, sustained the greater force of the strain, and there were others also above the bridge at a moderate distance; and if trunks of trees or vessels were floated down the river by barbarians for the purpose of destroying the work, the violence of such things might be diminished by these defenses and might not injure the bridge. Within ten days after the timber began to be collected the whole work was completed and the whole army led over." De Bello Gallico, Book IV, Chapter XVII.

Euboea. When permanent structures were needed stone stringers were sometimes used. An example of this kind of construction is found in

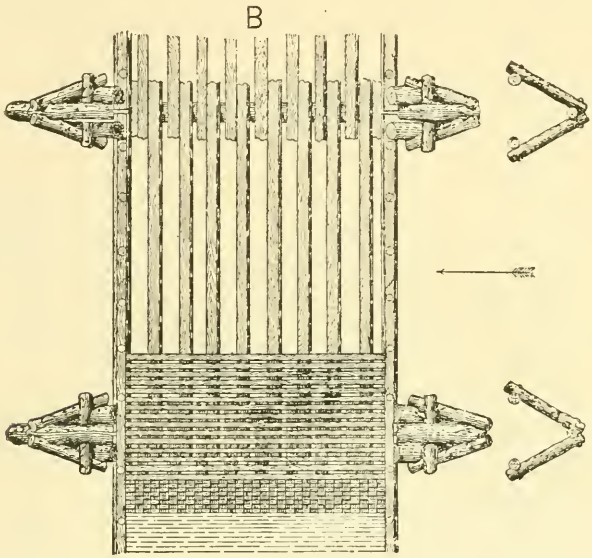

FIG. 32b.

the remains of a very ancient stone bridge, near Assos in Greece (see Fig. 33), which was explored in 1881, and is thus described by Mr. J. Thatcher Clarke.* "The piers are in plan of elongated diamond-shape and extend upon either side slightly beyond the bridgeway to a length of 3.6 meters. The masonry of these supports consists of large blocks carefully jointed and is particularly remarkable for the system of combining the stones by which the action of the current is resisted.

"Joggles cut twice upon each course make it impossible to displace any stone by lateral pressure without entirely overthrowing the heavy pier which present a minimum width to the stream."

Connecting these seventeen piers, whose centers were about 10 feet apart, four stone lintels, each about 10 feet long, 24 inches wide and 20 inches thick, were laid bonded together with swallow-tailed dowels of wood, in the manner universal in the Hellenic architecture of the 4th century, B. C.

In other ruins of Greek stone bridges there is no evidence to show that the true arch was used. Corbeled stonework, each course extend-

* Papers of the Archæological Institute of America—Classical Series I, page 129.

ing a few inches further toward the center of the stream than the one immediately under it, similar to the Chaldean brick-work, previously described, seems to have been the method generally employed. Remains indicating this are to be found at Pylos; and a portion of another stone bridge, with three approaches, is found in Messenia, built in the same manner.

Although the origin of the arch can be traced back to the Chaldeans

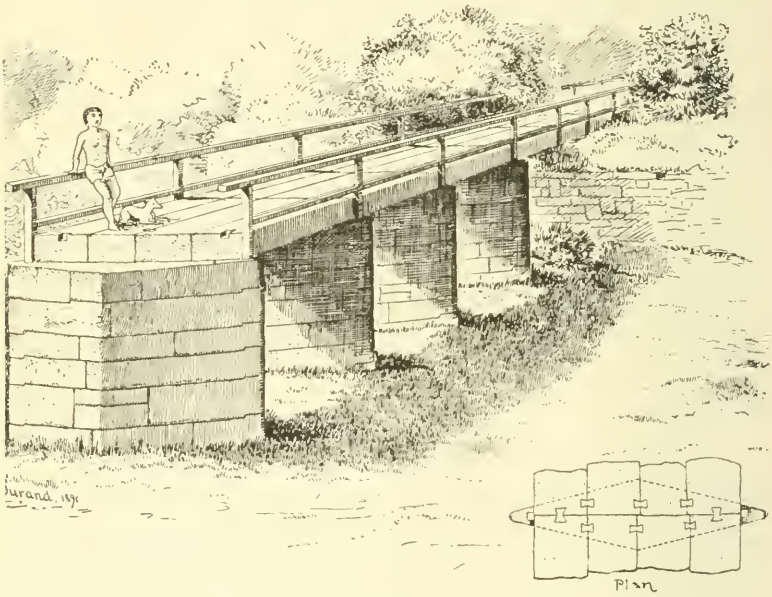

FIG. 33.

or the Assyrians, the Romans may be said to have been the first nation who used it constantly and consistently, as they understood the theory and practice almost as well as the engineers of to-day. An excellent example of arch work is to be found in the remains of the Stables of Mæcenas' Villa (see Fig. 34*), built before the Christian era. The Romans were also famous for the mortar which they used. This was made partly of pozzuolana, a volcanic earth, which was abundant in Italy. In the stone viaduct of seven arches 9 miles from Rome, on the way to Gabii, built

* Figs. 34, 35, 36 and 37 are redrawn from "Ruines de Rome," published by J. Hearne, London, early in this century.

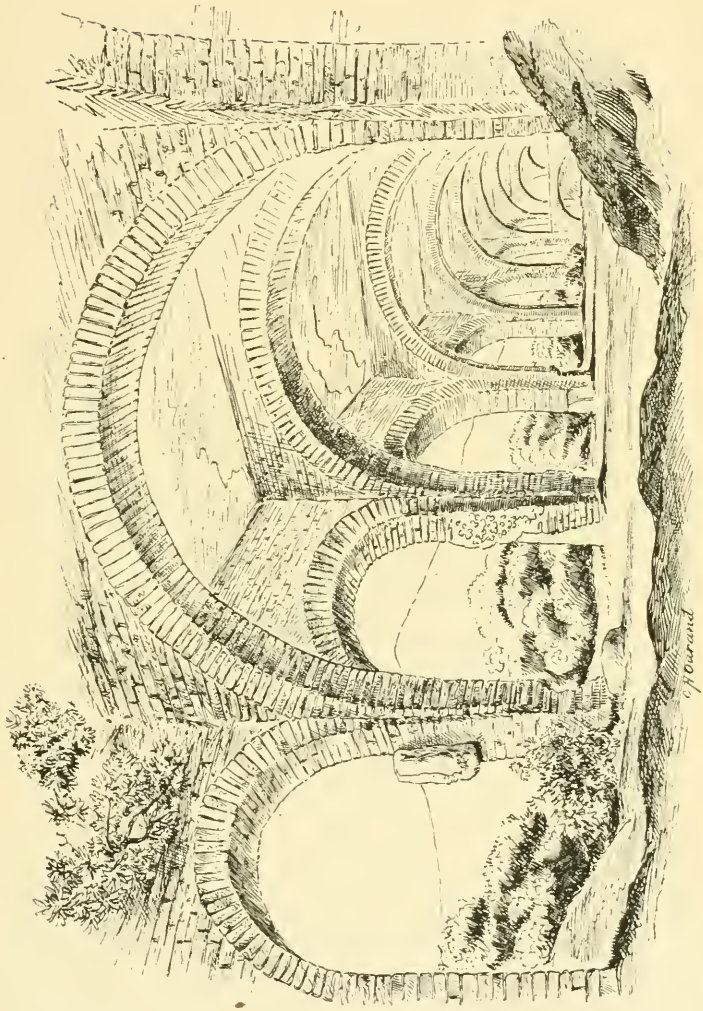

FIG. 34.

in the 2d century, B. C., and in the "Piscina Mirabile" (see Fig. 35) in Pozzuoli, near Naples, the same principles of masonry are employed as in our day.

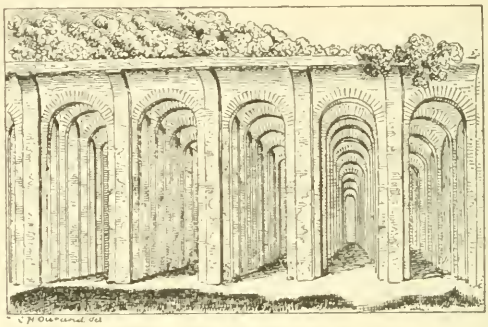

Fig. 35.

Upon the column of Trajan is a representation of the oldest bridge now standing on the Tiber, the Ponte de' Quattro Capi (see Fig. 36), built

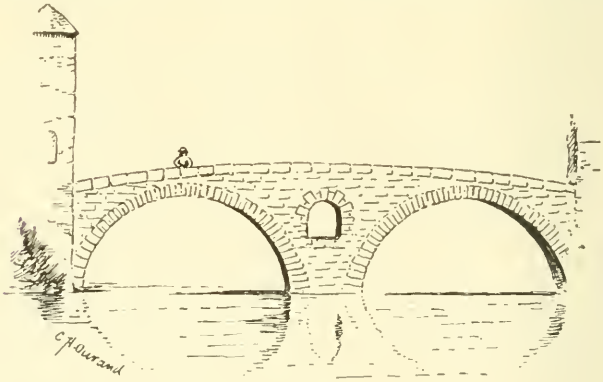

Fig. 36.

62, B. C.,* which connects the City of Rome with an island in the Tiber and consists of two graceful arches. The central pier is supported upon a foundation with a sharp edge against the stream—and the two large arches are connected by a third and narrow arch, which gives an appearance of grace to the whole structure that is seldom excelled even in our so-called æsthetic age. A high aqueduct bridge (see Fig. 37), was constructed with

* Called originally Pons Fabricius after the Consul under whose directions it was built.

a double tier of arches. The Romans built many arch bridges in the various countries which they conquered; and the mediæval bridge builders of England doubtless patterned after the remains of the Roman occupation.

The first road bridge in England, of which there is reliable record (I refer to that at Stratford, over the River Lea, a few miles east of London), was rebuilt in 1118 by Matilda, Queen Consort to Henry I. Speaking of the bridge, Stowe says: "The bridge of Stratford-le-Bow was arched like a bow—a rare piece of work, for before that the like had never been seen in England." This old bridge was kept in poor

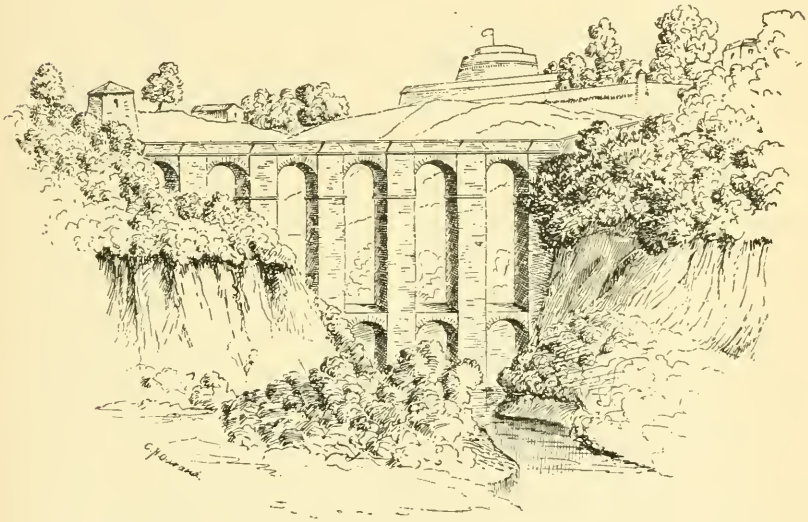

FIG. 37.

repair by begging aid from the passers-by; and finally during the reign of Queen Elizabeth, collections for that purpose were taken up in the churches, as the repairs were "a work of great necessity for the passage of victuals unto the inhabitants." The moneys collected from the churches not being sufficient for maintaining the bridges, we are told that in 1489 the Archbishop of Canterbury "adopted the expedient of publishing a remission from purgatory for thirty days to such persons as should give donations toward the repairs" of an arched stone bridge over the Medway. The early English bridges with their

chapels dedicated to various saints,* strongly resembled the cathedrals in architectural character.

Smiles states that "From the point at which the piers rose above the level of the stream, ribs of stone usually spanned the openings from one pier to the other, precisely similar to the Gothic arching of cathedrals and vaults of chapter-houses; and it is most probable that the bridges and cathedrals were built by the same class of workmen."

It was in the construction of the Westminster Bridge, 1738, that Labelye first used caissons in building the foundation of the piers. He had a number of water-tight chests made on shore and arranged to fit close alongside of each other. He floated these rafts over the spots destined for the piers, where they were permanently sunk, the top of each caisson being above high-water mark. The masonry was then laid within them and was carried up above the level of the stream, after which the timber sides were removed and the pier was left resting on the bottom. Submerged foundations were then protected by sheet-piling.

The Penepe, a suspension bridge—the cables of which are made of plant fiber, 4 inches in diameter and having a span of 131 feet, is described by Humboldt. It was built many years ago across the River Chambo, in Quito, South America. Over the river Tchin-tchin, in China, a suspension bridge, the floor of which is supported by five chains with vertical suspending rods, is so ancient that a superhuman origin is assigned to it by the natives. In India, noted for its early use of iron, suspension chain bridges were erected at a very early date, the links in the chains being composed of coils of drawn wire.

Mr. Theodore Cooper, in his very valuable paper on "American Railway Bridges," has covered the subject so thoroughly that it is only necessary for me to call attention to his record of American bridges built in the last century.†

* The old London bridge began in 1176 and completed thirty-three years afterwards, was dedicated to St. Thomas; the Bow Bridge to St. Catharine, and the one over the Weir to St. Nicholas.

† "The earliest bridges, where single timbers were not sufficient to stretch from bank to bank, were short spans supported on piles, or, where these could not be used, on timber cribs filled with stone. Where the conditions would not allow of structures of this character, arch spans were usually adopted." "In 1660, 'The Great Bridge,' as it was then called, was built across Charles River, between Old Cambridge and Brighton. It was a pile bridge." "In 1761, Samuel Sewell planned and built a bridge over York River, Maine, 270 feet long, supported on thirteen piers. Rebuilt in 1793." "In 1786, Mr. Sewell built a bridge over the Charles River, at Boston, 1 503 feet long, supported on seventy-five piers. A year or so later bridges on the same plan were built at Malden and Beverly, Mass." "In 1792 Colonel John P. Riddle built the Amoskeag Bridge, at Manchester, N. H. It was 556 feet long, and supported on five piers and two abutments. It was commenced on the 3d of August, 'at which time the timber was growing,

The timber bridge of 340 feet span, built across the Schuylkill River, near Philadelphia, during the early part of the century, will probably never be surpassed by a wooden structure. In an illustrated "Treatise on Bridge Architecture," by Thomas Pope, published in New York, in 1811, "in which the superior advantages of the flying lever bridge are fully proved," are described the principles of the cantilever bridge of timber, which had centuries before been used in China and Japan, in its primitive form.

The development of the modern iron bridge has followed very closely in the lines of other structures. Bridges of cast-iron came first, bridges of wrought-iron and of steel followed in order. In 1777, Abraham Darby built the first cast-iron bridge on record. This bridge crosses the Severn River in Colebrook-dale, England, and all the metal in it was cast at a foundry in the neighborhood. The arch was very nearly a semi-circle, the chord being about 100 feet. The second iron bridge was cast by Walker & Co., in Yorkshire, in 1795. It was intended to have been sent to America, but the speculator failing in his payments, the materials were used for the beautiful bridge over the Wear.* The span of this arch is 240 feet and elevated 100 feet above the water. Telford's iron bridge at Buildewas, in Shropshire, was finished during the latter part of the last century. The Southwark Bridge over the Thames, built by Rennie in 1818, was for many years the finest iron bridge in the world. "The Evolution of the Modern Railway Bridge" is fully discussed by Charles Davis Jameson, in Vol. XXXVI, page 478, *Popular Science Monthly*, February, 1890.

Modern Tunnels.—A tunnel 2 miles long, for a canal for the Thames, from Gravesend to Frindsbury, opposite Chatham, England, was com-

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and the rocks dispersed in the river,' and completed on September 29th." "Between 1785-92, Colonel Enoch Hale built over the Connecticut River, at Bellows Falls, a bridge 368 feet long, in two spans, taking advantage of a rock in the middle of the river for his center pier. The West Boston Bridge over the Charles River, 3 583 feet long, and supported on one hundred and eighty pile bents, was finished in 1793." "In 1795 a bridge was built over the Mohawk River, 960 feet long. In 1792, Timothy Palmer built the Essex-Merrimac Bridge over the Merrimac River, at Deer Island. In 1794, the bridge at Haverhill, was built by Timothy Palmer. In 1796 he built a bridge over the Potomac River, at Georgetown. In 1796, Rufus Graves built a bridge over the Connecticut River, at Hanover, N. H. In 1795 a bridge was erected at Holt's Rock, between Newbury and Haverhill. It was 1 000 feet in length and consisted of four arches and one draw-span. It was carried away by the ice in 1818. In 1796 a bridge was built between Harlem and Morrisania, over the Harlem River.

*Roads and Railroads—Author anon. Parker, London, 1839.

pleted in 1807. The Thames Tunnel (1826–40), of which Brunel was engineer, after many delays and mishaps, was completed in 1840, sixteen years after it was commenced. The first railroad tunnel in the United States was that built for the Alleghany Portage Railroad in 1831, under the direction of Solomon W. Roberts and Sylvester Welch. It was 901 feet long and 20 feet wide, being built for a double track. It was carefully lined with stone, the entrances being gracefully arched (see Fig. 38).

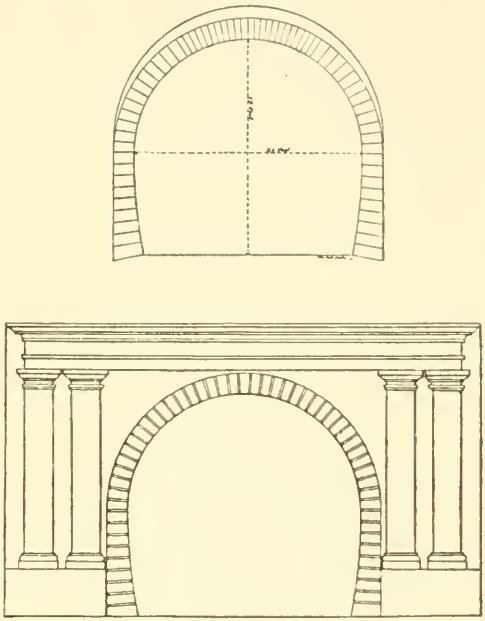

FIG. 38.

THE STEAMBOAT, CANAL AND RAILROAD ERA.

The early years of the century were destined to witness the beginning of an era in engineering activity, the results of which revolutionized the traffic of the world. The same year (1804) in which the first screw propeller was driven by steam on the Western Continent, Trevithick finished his first experimental locomotive driven by high-pressure steam; and the same year (1807) that witnessed Fulton's success with the paddle-wheel steamboats, found what proved to be the first locomotive to help man, in Trevithick's work-shop, almost complete.

A conflict of opinion in regard to the comparative merits of the canal and horse-tramway existed before the final location of the Erie Canal. The discussion led to the publication in 1812 of what was perhaps the most important contribution to the literature relating to early railway history. I refer to the pamphlet entitled: "Documents Tending to Prove the Superior Advantages of Railways and Steam Carriages over Canal Navigation," published by John Stevens, of Hoboken, N. J.*

* Printed by T. & J. Swords, New York, 1812; reprinted by the *Railroad Gazette*, 1882.

President Charles King, of Columbia College, N. Y., in an introductory note to the edition printed in 1852, pays this deserved tribute to the author: "Whosoever shall attentively read this pamphlet will perceive that the political, financial, commercial and military aspects of this great (railroad) question were all present to Colonel Stevens's mind," and this thirteen years before a locomotive was put successfully to work on a railroad. Notwithstanding the protests and elaborate arguments of Colonel Stevens, the New York authorities decided in favor of the canal.*

When Governor Clinton passed through the Erie Canal, soon after it was opened in 1825, on one corner of his special boat stood a cask of water from Lake Erie, and on the other corner a cask of water from the Hudson River. The completion of the canal was hailed with such enthusiasm that Governor Clinton was compelled to limp from the boat to the public halls, where speeches were made by and to him, the whole country being aroused.

After Stephenson's success with the locomotive on the Stockton and Darlington Railway, in 1825, many meetings were held to discuss the railroad question. In Pennsylvania, the Society of Internal Improvement, in the same year, collected a fund and sent William Strickland, an architect of ability, to England to investigate and report upon engineering methods there. The following abstract from his instructions indicate the crude ideas that existed in regard to the usefulness of the civil engineer:

> "We desire that you furnish such minute and particular descriptions, plans, drawings, sections, estimates and directions, as, possessed of them, that these works may be executed in Pennsylvania without the superintendence of a civil engineer of superior skill and science."

A veteran Member of this Society, who recently passed away † from the scene of action in which he played such an important part, placed on record his reminiscences of the first five years of the railroad era, in the *Railroad Gazette*, in 1884.

The first English railway act was passed by Parliament in 1794; that for tramroads in 1800. In 1804 the general charter was obtained by the

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* Curiously enough, Fulton's first efforts in steamboat invention were in the direction of a tow boat for the canal; and the first screw propeller boat sent to America was imported for this service by Commodore Stockton for the Delaware and Raritan Canal. The earlier railways were built to connect the termini of inland navigation where it was impracticable to construct canals.

† Horatio Allen died December 31st. 1889.

Surrey road, which was to be operated by horses. It was opened in 1805. A horse railroad from Leeds to Liverpool was opened in 1811, and the first steam railroad, the Stockton and Darlington, was projected in 1820 and completed in 1825.

The first railroad in Austria for passengers and freight traffic, was laid between Budweis and Lintz. It was projected in 1819, by a Convention held at Dresden, as a railway to be operated by horses and stationary engines and cables. The surveys were begun in 1822, and the charter was issued in 1824, and 39 miles were completed by 1828.

The first railway of any considerable extent in France, from St. Etienne to Andrezieux, was begun in 1825 and finished in 1828. It formed a continuation of the road from St. Etienne to Lyons, a distance of 34½ miles, and was opened throughout in the early part of 1831, having been finished five years from the commencement of the work.

In 1831 King Leopold of Belgium proclaimed a law, according to which a system of railroads was to be instituted throughout the whole kingdom of Belgium.* De Theux and his successor, Nothomb, were deputized to construct the system of railroads, at the expense of the State. At Antwerp and Ostend the railroads were to lead to the seaports, on two points connecting with France and on one point with Prussia (Germany). The first road was opened in 1835.

In 1836 the first charter for a railroad in Russia was granted by the Czar, and the first road constructed, which was from St. Petersburg to Zarshaloe, was opened in 1837, and the second from St. Petersburg to Peterhof in 1838.

The first railroad in Holland was commenced in 1836, to connect Amsterdam with Harlem. And the second was laid from Amsterdam to Arnheim. King William guaranteed a dividend of 4½ per cent. per annum to the stockholders from his own private property.

The first railway in the United States of which there is reliable record was laid in Delaware County, Pa., in 1810, from Leiper's stone quarry to the Delaware River. This road, as well as the granite railroad at Quincy, Mass. (laid in 1826), and the coal roads at Mauch Chunk, Pa., (laid in 1827), were originally intended to be operated by horse-power. Of the steam railroads the Baltimore and Ohio was one of the earliest, the corner-stone having been laid July 4th, 1828. The Mohawk and Hud-

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*See *Journal of Franklin Institute*, September, 1839.

son, and the South Carolina were put under contract in 1829, the Camden and Amboy 1830, the Philadelphia and Germantown, and Philadelphia and Columbia in 1831. Thus in the decade from 1825 to 1835 a new branch was added to the profession of the civil engineer, and men whose experience had been gained in other departments were called into the new and untried field of railway construction.*

The English *Railway Official Gazette* for May, 1886, states that railways were introduced in various countries on the following dates:

England	September 27th, 1825
Austria	September 30th, 1828
France	October 1st, 1828
United States	December 28th, 1829
Belgium	May 3d, 1835
Germany	December 7th, 1835
Island of Cuba	In the year 1837
Russia	April 4th, 1838
Italy	September, 1839
Switzerland	July 15th, 1844
Jamaica	November 21st, 1845
Spain	October 24th, 1848
Canada	May, 1850
Mexico	In the year 1850
Peru	In the year 1850
Sweden	In the year 1851
Chili	January, 1852
East Indies	April 18th, 1853
Norway	July, 1853
Portugal	In the year 1854
Brazil	April 30th, 1854
Victoria	September 14th, 1854
Columbia	January 28th, 1855
New South Wales	September 25th, 1855
Egypt	January, 1856
Middle Australia	April 21st, 1856
Natal	June 26th, 1860
Turkey	October 4th, 1860

Magnetism and Electricity.

The beginnings of electrical science, if we except the knowledge of the magnet and of frictional electricity, and of Franklin's experiments

*Ashbel Welch, in his presidential address, 1882, has placed upon record the following facts concerning the early American railway engineers: "American engineers and managers have often shown that poverty is the mother of invention. For example, they used cross-ties as a temporary substitute, because too poor to buy stone blocks, and so made good roads, because they were not rich enough to make bad ones. American engineers are, or at any rate were, trained on short allowance of money. As that is the best engineering which accomplishes the purpose at the least cost in the long run, American engineering ought to be of the best. They were not scientific men, but knew by intuition what other men knew by calculation."

with the kite and Leyden jar, are within the memory of many now living. To the patient investigations of the properties of the magnetic needle* by Oerstead and Arago we are indebted for the inception of the discovery of the principles of electro-magnetism which have been put into practical use during the last fifty or sixty years.

The earliest proposition to use the needle otherwise than in the compass, that I have found, is recorded in the dialogues by Galileo † (about 1630) in which Sagredus, one of his myths, is made to anticipate the invention of the needle telegraph in this remarkable manner:

"You remind me of one who offered to sell me a secret art, by which, through the attraction of a certain magnet needle, it would be possible to converse across a space of 2 000 or 3 000 miles. I said to him that I would willingly become the purchaser, provided only that I might first made a trial of the art, and that it would be sufficient for the purpose if I were to place myself in one corner of the sofa, and he in the other. He replied that in so short a distance the action would be scarcely discernible; so I dismissed the fellow, and said that it was not convenient for me just then to travel into Egypt or Muscovy for the purpose of trying the experiment, but that if he chose to go there himself I would remain in Venice and attend to the rest."

But two long centuries were doomed to elapse before the dream of Galileo was to be realized by Wheatstone.

Notwithstanding the triumphs of the European scientists in the field of investigation, America was destined to number among her sons, Henry, Vail and Morse, the triumvirate‡ to whom we owe the introduction of that system of magnetic telegraphy now almost universally used.

The triumphs of Davy, Nollet, Malderon, Siemens, and Gramme, the pioneers in the field of electrical lighting, which were achieved before the middle of the century, have been eclipsed by another American whose marvelous discoveries will cause his name to be remembered as long as darkness shall disappear before the rays of the electric lamp.

The Jacobi electric motor experimented with in 1834, was followed by others invented by Davenport, 1837; Stimpson, 1838; Cook, 1840; Froment, in 1845; Du Moncel, 1851; Hall, 1851; Page, 1854;‖ and a host of others, until Fontaine and Gramme worked an electric pump 1 kilo-

*According to Klaproth (Lettre a M. le Baron Humboldt sur l'invention de la Boussole, Paris, 1834), the Chinese sailors used the mariner's compass B. C. 2634, over 4,500 years ago.

† Galilei Systema Cosmeum Dialogus I. Leyden Edition, 1700.

‡ The ability to communicate signals by sound over long distances was demonstrated by Henry in 1828. Vail's claims to the invention of the alphabet and the construction of the first instruments appear to be well founded. Morse's labors in putting these discoveries and inventions into practical use for the public service likewise gave him fame and fortune.

‖ Page's motor, based upon the principle of attraction of solenoids, was brought into public notice in 1850, at a lecture delivered before the Smithsonian Institution at Washington.

meter distant from the engine, at the Vienna Exposition, 1873. "The first real application of the principle of the reversibility of electric machines and at the same time the first real example of the electric transport of force."* The experiments of Siemens and Halske at the Berlin Exposition of 1879, demonstrated the fact that the electric motor could be practically applied to tramroads, and the first electric railway constructed for traffic between Lichterfelde and the Cadet's College, near Berlin, 1.59 miles long, was formally opened May 12th, 1881; the electricity being conveyed by an insulated wire.

Later in the year 1881, the Electric Railway at Paris, from Palais de l'Industrie to Place de la Concorde, also constructed by Siemens and Halske, was put in operation, the current being conveyed by an overhead wire. In 1882, the first electric locomotive driven by a storage battery, was placed in service at the Bleaching Establishment belonging to Duchesne-Fournet, at Breuil-en-Auge, near Lisieux, France, upon a small railway laid down on the meadows, to collect linen. The boat "Electricity," 27 feet long, was driven against the current on the Thames, with a speed of 9 miles per hour, September 8th, 1882, the machinery being operated by the accumulators of the E. P. S. Co.

Engineering Societies.

In 1771, John Smeaton, F. R. S., projected and established an association or society of engineers in London, and during an interval of twenty years, the number of members increased to sixty-five, of whom fifteen were practicing engineers. Among them we find the names of Boulton, Edwards, Golborne, Grundy, Jessop, Mylne, Nickalls, Joseph Priestly, Rennie, Watson, Watt, Whitworth and Whitehurst. The residue was composed of amateurs, ingenious mechanics and architects. In May, 1792, this society was dissolved in consequence of dissension, and a reorganization under a better form, though intended, was not accomplished until after the death of Mr. Smeaton, which occurred in October, 1792. The first meeting of the new "Society of Civil Engineers" was held on April 15th, 1793, Jessop, Mylne, Rennie and Whitworth being the organizers. By the new constitution the society was divided into three classes: Class I.—Ordinary members consisted of practicing engineers. Class II.—Honorary members, men of science and gentlemen of rank

* Electricity as a Motive Power. Du Moncel, Geraldy and Wharton. London, 1883.

and fortune who were interested in the subject of civil engineering. Class III.—Honorary members were persons not civil engineers, whose professions and employments had brought them into close connection with civil engineering. The meetings were held at the "Crown and Anchor" in the Strand, every alternate Friday during the sessions of Parliament.

This was the origin of what has since become the (English) Institution of Civil Engineers, established in 1818, and incorporated in 1828. And upon the roster of this society the names of many of the most distinguished engineers in the world have appeared.

In America many civil engineers connected themselves with the Franklin Institute after its establishment in 1824, and for years the journal of that institution was the repository of the current engineering literature, foreign and American. In 1836, a number of the engineers connected with the Charleston and Cincinnati Railroad attempted to establish the National Society of Civil Engineers. Among those who took active part in the movement were Messrs. McNeil and Whistler, graduates of West Point, who became prominent railroad engineers. Their action did not meet with the encouragement expected, and the society was short-lived. In 1839, another and a similar attempt was made at Baltimore by the engineers of the Baltimore and Ohio Railroad, and the other railways in the neighborhood, but beyond holding a few meetings nothing was accomplished. In 1841, "The American Institute of Engineers" was formed at Albany, N. Y., but it also survived a very short time. In 1848, the Boston Society of Civil Engineers was chartered.

The first meeting of what afterward became the American Society of Civil Engineers, was held at the Croton Aqueduct office, New York City, November, 1852.

From an article which appeared in the *Engineering News*, March 8th, 1890, and which Colonel Julius W. Adams advises me is authentic, I have extracted the following very interesting account of the circumstances through which this Society was founded:

"In the autumn of 1852, among the many engineers then in New York, was James Laurie, a Scotchman, who came to this country in 1831–32, who earnestly advocated the necessity, and probable feasibility, of the success of such a society, notwithstanding the failure which had attended all previous attempts to that end. The meetings of those with whom he communicated, were held in the rotunda in the Park Croton Aqueduct office, and resulted in the preparation of a paper published in the *Herald*, addressed to the civil engineers of the country, urging upon

them the importance of forming such a society, and proposing the assemblage of delegates favorable thereto, at a day named, some six or eight weeks in advance. The paper was an official call, signed by the secretary, and it was supposed that the place assigned for the meeting, being the office of A. W. Craven, Chief Engineer of the Croton Aqueduct, New York, was sufficient evidence that the undertaking was in respectable hands.

"The day arrived, November 5th, 1852, and with it from the entire country came no less than twelve engineers, whose names are recorded in the society annals, in the following order: Julius W. Adams, James Laurie, Thomas A. Emmet, J. W. Ayres, Edward Gardner, W. H. Talcott, R. B. Gorsuch, William H. Morrell, William H. Siddell, S. S. Post, A. W. Craven, George S. Greene.

"It was hoped that there would have been some individuals, who, if unable to attend, would at least offer the right hand of fellowship so far as to give written assurance that they were with us in heart, but there were none such, and we gravely proceeded to organize the society by electing officers and adopting a constitution and by-laws. Mr. Laurie was elected President, and Mr. Gorsuch, an assistant in the Croton Aqueduct office, was elected Secretary and Custodian of the Records. Mr. Laurie presented the draft of a constitution which he had prepared, and which, after discussion, was adopted section by section, and which was substantially the organic law of the society for many years."

Upon the roll of members for 1852, 1853 and 1854, I find among others the following names: 1852—John A. Roebling, Isaac C. Chesbrough, Robert N. Brown, James P. Kirkwood, Stephen Chester, Simeon Post, Abram S. Hewitt. 1853—William J. M'Alpine, W. H. Talcott, James O. Morse, Alexander Dallas Bache, Joseph Swift, John James Abert, Joseph G. Totten, Dennis H. Mahan, Stephen H. Long, Henry Burden, Moncure Robinson. 1854—Zerah Colburn, Horatio Allen.

The discouragement which the first members of the Society met with in its early days, is described in the annual presidential address delivered in June, 1870, by the President of the Society, Mr. A. W. Craven.*

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*See *Transactions* Am. Soc. C. E., June, 1870. "Our Society, as you all know, was first formally organized in the year 1852. At that time there was scarcely enough members within immediate vicinity of New York to supply incumbents for the offices alone. Still we met, and strove our best to nurse the infant in whose health and growth we all had so deep an interest. We met, as our early records show, to the number of seven, five, sometimes three on an evening, and every man present was an official. We could not afford to hire a room, and so our 'corporal's guard,' or rather our guard of corporals, met at night in one of the vacant rooms of the Croton Aqueduct Department in this city. There we may be said to have worked hard; for even if we did nothing else, to courageously and persistently attend such meetings was to work hard. The struggle lasted three years, until at last, in March, 1855, we were obliged to succumb. Our failure seemed to be so complete, that with some of us there was no hope of recuperation, and had there been any means of returning to absent members their respective portions of the money remaining in our hands, the majority of the active members would have counseled such return. Some however, still retained their courage, and urged the careful investment of our funds and the safe storage of our books and papers until hoped-for brighter days. The result has proved the value of that courage and the wisdom of that advice. Our syncope lasted

An examination of a comparative statement of the number of persons connected with the Society November 1st, 1871, and January 1st, 1891, shows a most gratifying growth in nineteen years:

	1871.	1891.
Members	212	1 090
Associates	5	61
Fellows	48	51
Juniors		215
	265	1 417

Engineering Schools.

Already toward the end of the last century the investigations of such pioneers as Franklin and Priestly suggested to those who projected institutions of engineering the establishment of courses for the study of the natural sciences. The extension of the course in surveying and draughting, which was studied in many of the earlier schools, finally developed into the establishment of the chair of engineering. As early as 1826, St. John's College, Maryland, had a course of mathematics, civil engineering and military tactics, of which Captain Thomas E. Sudler, graduate of West Point (No. 234), was the professor.

In 1834 the University of the City of New York established a technical course under the charge of Prof. Norton, who occupied the chair of physics, and Dr. Charles W. Hackley,* Professor of Mathematics. Both of these gentlemen were graduates of the Military Academy at West Point. Practical training in the use of the theodolite, level and surveying instruments was given to students under their direction.

twelve years; and when, resolved upon one more strong effort for life, we came together in October, 1867, we started with a fund which added materially to our strength and spirits. We took our present rooms, and, so far as our limited means permitted, we tried to make them attractive. We were no longer vagrants. We had at last established an actual habitation of our own; a point to which each member might come as to his own house, and at which he might meet those who, with him, were interested in a common enterprise, and so we all felt renewed hope. That hope has, in my opinion, been justified by events; for, although we are still far behind what we all desire to be, and though some impatient hearts are still unsatisfied, we have, considering the character of our work, and the age of our organization, made what may fairly be called large strides. Look at the facts: At the time of re-gathering for this work, the members on our old register, known to be alive and thought to be willing to aid in the attempt to revive the Society, numbered in all only twenty-eight. Of those who were present in the city to speak positively to that point, there were but thirteen. This was in October, 1867, not yet three years ago. Now we count upon our rolls 179 regular members and the number is constantly increasing."

*Dr. Hackley was Professor of Mathematics at Columbia College for many years.

Scanzin's "French Text-book of Engineering" was the authority on engineering subjects for several years after 1836. Scanzin was regarded by Napoleon as the best engineer living.*

In the reports of the United States Bureau of Education it will be found that courses of civil engineering were established in various colleges during the years mentioned: 1836—Rensselaer Polytechnic Institute, Troy, N. Y. 1845—School of Civil Engineering, Union College, Schenectady, N. Y. 1847—Sheffield Scientific School, Yale College. 1851—Chandler Scientific Department, Dartmouth College, Hanover, N. H.; Thayer School of Civil Engineering (post graduates from Chandler) a few years later; School of Technology, Lehigh University, South Bethlehem, Pa. 1864—School of Mines, Columbia College, New York, N. Y. 1865—Massachusetts Institute of Technology, Boston, Mass. 1866—Pardee Scientific Department, Lafayette College, Easton, Pa. 1872—Towne Scientific School, University of Pennsylvania. 1873—John C. Green School of Science, College of New Jersey, Princeton.

Courses in military and civil engineering were established at several military schools in the Southern States soon after the nullification movement of 1832. Prominent among this number were: the Virginia Military Institute at Lexington, Va., established in 1839.

Lewis College, Northfield, Vt., long known as Norwich University, established a Military College at a very early date, and many other military schools and colleges, where civil engineering was taught, were established throughout the United States. From these and other colleges and schools that have since been established, the engineers of the modern railways and other public works are annually recruited. Profiting by the experiences of their predecessors, and with every opportunity for study, and every appliance for investigation, graduates from these institutions are fitted to begin their active duties with advantages vastly greater than were enjoyed by the young men who swung the axe or held the chain or rod sixty or seventy years ago.

Conclusion.

I have attempted to place on record the circumstances that have led to the beginnings of engineering science. Happily, the crack of the

* It is related that while Napoleon was in camp at Boulogne, requiring some information from Scanzin, he sent for him to come to his tent. Scanzin came, but Napoleon noticing he was faint for want of food, was so anxious for the information that he ordered the dinner sent to his own tent, and made memoranda from Scanzin's dictation while he ate.

Egyptian slave whip has given place to the whistle of the steam excavator; and the tugging song chanted by the thousands hauling at the ropes to draw or hoist the monolith * has died away, to be heard no more while man shall utilize the generated forces. The engineer of to-day, unlike his early predecessor, is able to dredge the sea of ideas and to call specialists in every branch of science to his aid. The experience of the chemist, the metallurgist and electrician he can obtain to assist him in solving the problems now presented. He may, indeed, cull from every branch of science. With these unlimited opportunities, are his successes more praiseworthy than those of his predecessors forty or fifty centuries ago?

If the demands of what we are pleased to call our higher civilization should exhaust our mines of coal, our wells of oil and gas, and our beds of ore, so that steam and iron should no longer be the slaves of man, could the modern engineer erect so magnificent an edifice as Karnak, bore so wonderful a tunnel as the Grotto of Posilippo, or construct such a satisfactory system for water supply as Rome enjoyed during the Augustan age?

ILLUSTRATIONS FOR PAPER.

Fig. 1. Egyptian Brick stamped with the Royal Ovals.
Fig. 2. Assyrian Masonry. Wall of sun-dried bricks faced with stone. (Khorsabad).
Fig. 3. Brick with Nebuchadnezzar's stamp, from the Louvre. Redrawn from "Art in Chaldea and Assyria," by Perrot and Chipiez.
Fig. 4. Grotto at Posilippo, near Naples. Redrawn from "Ruines de Rome."
Fig. 5. Chaldean Corbeled Vault of Bricks.
Fig. 6 Arch in Sewer at Khorsabad. Compiled from Place's Nineveh. by Perrot and Chipiez.
Fig. 7. Greek Corbeled False Arch.
Fig. 8. Greek Corbeled False Arch.
Fig. 9. False Arch in West Wall of Ancient City of Assos, Greece. Drawn from photograph furnished by Mr. J. S. Diller, U. S. Geological Survey.

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* See frontispiece, Vol. II, Ancient Egyptians, by Wilkinson, "Mode of Transporting a Colossus from the Quarry."

Fig. 10. Corbeled Portal in West Wall, Assos. Redrawn from illustration in "Papers of the Archæological Institute of America," by J. Thatcher Clarke.
Fig. 11. Section of Roman road through Culvert.
Fig. 12. Old Measuring Line, 1720.
Fig. 13. Toise, 1720.
Fig. 14. Surveyor's Chain, 1720.
Fig. 15. Odometer, 1720.
12, 13, 14 and 15 are redrawn from "Bion's Mathematical Instruments," Paris, 1723.
Fig. 16. Water Level, 1720.
Fig. 17. Air Level and Tube, 1720.
Fig. 18. Air Telescope Level, 1720.
Figs. 19, 20. Plumb Levels, 1720.
Figs. 21, 22. Plumb Telescope Levels, 1720.
16, 17, 18, 19, 20, 21 and 22 are redrawn from "Bion's Mathematical Instruments," Paris, 1723.
Fig. 23. Instruments of the Geometrician. Redrawn from "Nomenclature and Pictures of all the Chief Things that are in the World," published by Comenius in 1658.
Fig. 24. Surveyor's Cross, 1720.
Fig. 25. Magnetic Compass, 1720.
Fig. 26. Plane Table, 1720.
Fig. 27. Circumferenter, 1720.
Fig. 28. Theodolite, 1720.
24, 25, 26, 27 and 28 are redrawn from "Bion's Mathematical Instruments," Paris, 1723.
Fig. 29. Engines.
Fig. 30. Horse-mill, Water-mill, etc.
Fig. 31. Ancient Lathe.
29, 30, 31, redrawn from "Nomenclature and Pictures of all the Chief Things that are in the World," published by Comenius in 1658.
Fig. 32. Cæsar's Bridge.
Fig. 33. Ancient Greek Bridge at Assos. Compiled from "Papers of the Archæological Institute of America"—Classical Series I.
Fig. 34. Stables of Mæcenas' Villa. Redrawn from "Ruines de Rome."
Fig. 35. "Piscina Mirabile" (The wonderful fish ponds), near Naples.
Fig. 36. Pont de' Quattro Capi, a bridge over the Tiber, Rome.
35 and 36 are redrawn from "Ruines de Rome."
Fig. 37. Aqueduct Bridge near Rome. Redrawn from "Ruines de Rome."
Fig. 38. Tunnel through the Alleghany Mountains. The first railway tunnel in America.

DISCUSSION.

Clemens Herschel, M. Am. Soc. C. E.—It has always seemed to me a very interesting study as to who actually was the first civil engineer. I believe James Brindley, one of the first to do a civil engineer's work in Great Britain, called himself "Millwright" to the end of his days. But the man who, in English-speaking countries, first signed himself Civil Engineer, and by that fact, first put the crown upon his own head, so to speak, was John Smeaton. He signed himself "John Smeaton, Civil Engineer," and, so far as I know, was the first man in English speaking countries so to do. It is curious to observe that he also was the first expert witness, under our system of judicature. He was an expert witness in the law case of Folkes *vs.* Chadd (1782), and a contest arising as to whether a man could, from the witness stand, give an opinion, it was ruled in his favor; no doubt on account of his eminence in his profession, and of the regard in which he was held by all his contemporaries. He was the first civil engineer and also the first expert witness, and yet that was only about one hundred years ago.

There is another addition I would like to make to the paper. Among the American societies of civil engineers now in existence, there is the Boston Society of Civil Engineers, organized in 1848 and living under its charter granted in 1851; the oldest society of civil engineers in existence in the United States, I believe.

William E. Merrill, M. Am. Soc. C. E.—In reference to the question of early engineering societies in the United States, I think that the author has overlooked the Essayon's Club of Willet's Point, New York, a club composed of officers on duty at the Engineer School of Practice, which was organized in January, 1868.

I noticed that the author speaks of the Corps of Engineers as dating from 1824. I do not quite understand what he means by this, as there has always been an engineer corps in the army of the United States, even during the Revolution.

Mr. Watkins.—The point I wanted to make was that that was the date when the first army engineers were employed as civil engineers under the law.

Colonel Merrill.—As a matter of interest I will give a short history of the Corps of Engineers of the United States Army.

One of the earliest Acts of the Continental Congress, provided for the appointment of chief and assistant engineers, attached to the various armies, with the ranks of colonel and captain respectively. This act was passed in June, 1775, and therefore it antedated the Declaration of Independence by more than a year. From that date until the close of the Revolutionary War engineer officers were on duty with all the

American armies, the great majority being foreigners from the armies of Europe. The Chief of Engineers during the Revolution was General Du Portail, and the second in command was Colonel Thaddeus Kosciusko. After the Treaty of Peace in 1783, all the military forces, including the Corps of Engineers, were disbanded, and the corps was not revived until 1794, since which date its organization has frequently been changed, but its service has been continuous.

The Corps of Topographical Engineers had its origin in 1777, when a "Geographer and Surveyor of the Roads" was appointed "for service with the army." After the close of the war the geographer became "surveyor of the public lands," and ceased to be connected with the military service. Topographical Engineers appear again in 1813, when four majors and four captains were appointed to serve in the war then under way. This corps was mustered out in 1815, but two majors were temporarily retained to complete their maps, and in the following year a corps of topographical engineers was made a part of the general staff of the army. In 1818 it was attached to the Corps of Engineers as a subordinate branch, and this connection continued until 1831, when it became a distinct bureau of the War Department. In 1863 the Corps of Topographical Engineers ceased to exist by being merged into the Corps of Engineers.

The civil history of the Corps of Engineers begins in 1824, when the Act of April 30th ordered the President to have surveys made of such roads and canals as he might deem of national importance. The general direction of these surveys was confided to a board consisting of two engineer officers and one civil engineer, with an office force of three engineer officers, and a field force of twelve engineer officers and six civil engineers. The majority of the engineer officers connected with the above mentioned surveys belonged to the topographical branch. The laws of the United States permit the President to assign engineer officers to any duty that he may choose, and this accounts for the singular duties which they sometimes have been called upon to perform.

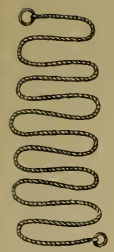
I should like to refer to one other item. Mr. Watkins mentioned the name of Major L'Enfant, an engineer officer of French birth. He is the father of the City of Washington, once a city of wastes, magnificent only in its distances, but now the handsomest city in America, and one of the gems of the world. Its marvelous uprising was mainly due to the fact, that an adequate foundation for the metropolis of a great nation had been laid by an engineer, before the soil was broken for the first house. The name of the man who made such things possible should always be held in honorable memory, especially by his professional descendants.

D. J. Whittemore, Past President Am. Soc. C. E.—In confirmation of the author of this exceedingly interesting paper, in his statement of the first maker of the American transit, I desire to say that many years ago, Alfred Young, son of William J. Young, was for a time in the same

corps with myself, and from him, and also from his father, whom I had the pleasure of meeting later, I became somewhat conversant with the subject of instrument manufacture in this country. My impression is that William James Young, an Englishman by birth, constructed the first two graduating engines, worthy of the name, in America. The plans for the largest were made by Jackson Young, under the supervision of William J. Young. After many changes the engine was constructed, and he, with Mr. L. N. Watson and Alfred Young, spent the best part of four years in its perfection, over $5 000 being spent in workmen's wages alone on the construction and truing of the main screws. Great difficulty was experienced by Mr. Young in procuring proper lenses; and at his solicitation, an optician named Worth, came to this country, who located first at New York. His son, Alfred Young, was sent to Worth to learn the methods of lens making, but finally the establishment was brought to Philadelphia.

Many of the instruments made in America and used by our Government were graduated upon Young's engine. The first transit used by me was one of the first, but not the first, made by Mr. Young, and was on exhibition at the Centennial Exposition at Philadelphia, as being the oldest then obtainable; since that time there was found at Altoona one of the very first made by Mr. Young. Both of these instruments are now in the possession of Young & Sons, at Philadelphia.

It is believed that the first use made of William J. Young's transit, was on the construction of the State road from Philadelphia to Harrisburg. For the purpose for which it was designed, I think it may be considered an American invention. It has driven the theodolite entirely from the field, at least in this country.

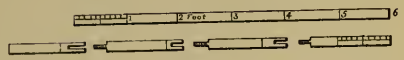


Line

FIG. 12.

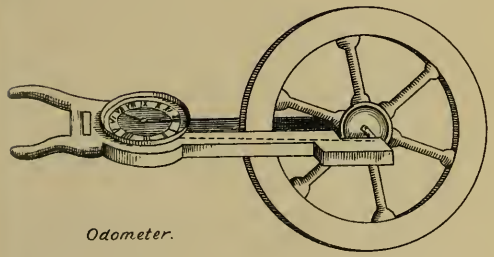
Chain.

FIG. 14.



Toises.

FIG. 13



Odometer.

FIG. 15

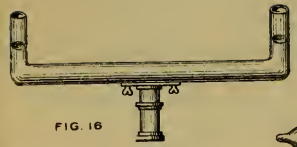


FIG. 16

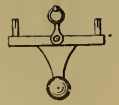


FIG. 17.

FIG. 18.

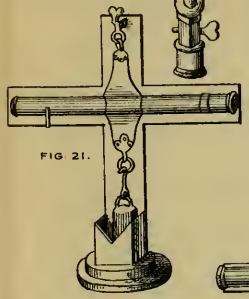


FIG. 21.

Levels.

FIG. 19.

FIG. 20.

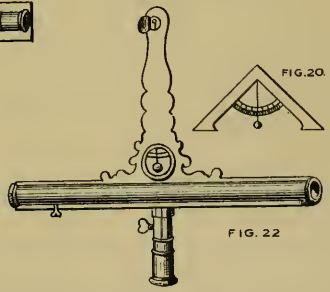
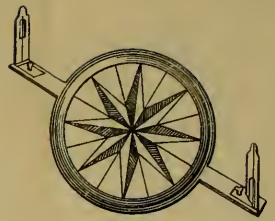


FIG. 22

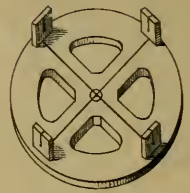


Circumferentor.

FIG. 24.

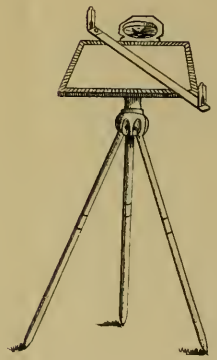
Compass

FIG. 25.



Surveyor's Cross.

FIG. 27.



Plane Table.

FIG. 26.

Theodolite

FIG. 28

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473.

(Vol. XXIV.—May, 1891.)

SOME DETAILS OF VALVES AND OTHER APPARATUS IN USE BY THE NATIONAL WATER WORKS COMPANY AT KANSAS CITY, MO.

FREDERICK E. SICKELS, M. Am. Soc. C. E.

The machine shown in Plate XXVIII is used by the National Water Works Company at Kansas City, Missouri. The writer designed it under the impression that it was a new contrivance. Investigation showed it to be an old invention. It is serviceable in cases where large connections are to be made without shutting off the water. The center bolt *C* may be tapped into the pipe before the machine is placed on it, as shown; or a short tap-bolt may be inserted by the use of an ordinary pipe-tapping machine. (See Fig. B.) After the circular-cutter *A* has cut the piece out of the pipe *H*, it, together with the cutting apparatus, is withdrawn, the valve is shut and the cutting apparatus is removed. The cutting tube *D* can be made of a piece of thick hydraulic tubing, and turned by inserting bars into holes *G*. This arrangement was used to save expense in construction. No doubt a large rachet-wrench to turn the tube would do the work of cutting faster. The cutter-head *O* is to cut

an 8-inch hole, and as here shown has a ring *R* to fit *O*, and thus increase the size so as to bore a 12-inch hole. By putting larger rings on the cutter-head, larger holes can be bored as may be required. The bands *S*, to hold the saddle to place, must be proportioned in number and strength to the size of the saddle and the water pressure. Although this machine has no patented devices such as have been made the subjects of patents at different dates, it works very well. The large machine was found to work well in cutting holes 16 inches in diameter out of a 36-inch pipe, and no doubt much larger holes could be cut, it being only necessary to increase the size of the cutter-head *O* by extra rings.

Plate XXIX shows a pressure regulating valve, the piston of which is water-packed. It is extremely desirable in a machine of this kind that not the slightest lateral pressure should come upon the piston, as the least friction will wear so as to cause a leak. The cylinder must be fixed exactly vertical, and the weight must be placed so as to act directly vertical downward upon it. To protect the piston from any lateral action the lower portion of the rod (*D*) is guided, and acts upon a shorter rod (*E*) which is also guided, so that any lateral force incidentally coming upon the weight will not be transmitted to the piston of the water cylinder. The stop-nuts (*HH*) are provided to limit the opening and closing motion of the valve so that it may not open more than enough to supply the greatest demand, and may not close beyond the opening required to supply the least demand. In the case where the machine is now used the greatest demand is at the rate of 4 000 000 gallons per day, and the least demand is very small. The pipe broken off at (*C*) connects to the low pressure side, and should be provided with a valve (*K*) to limit the speed at which the piston will move, so that the main valve may not open or close too suddenly. The rings (*G*) are made of brass and forced over the cast-iron piston. The section (*AB*) shows partitions (*I*) cast in the water-grooves of the rings (*G*) to prevent any water that may pass upward from running around from one side of the plunger to the other, and to thus baffle the leak in escaping entirely through the whole length of the plunger. After these rings have worn loose they may be stretched and a strip of tin put behind them. If care is taken in the fitting of the rings they will last without repair while in constant use, for several years.

The rod from the top of the valve that extends through the plunger should be (as here shown) left free for lateral motion at both ends to

provide for wear or any inaccuracy in fitting up; but the important parts should be finished by a superior workman, using a first-class lathe, to insure success.

When this machine is used where the water contains sediment, the pipe *C* should be connected to a drum to permit the water to settle before it reaches the cylinder, as is done in the case where the valve is now in use.

Where the water is always free from sediment no settling drum is necessary. The machine, as here shown, occupies great length; the valve is in the basement and the weights are above the next floor. It has been in operation for some time and has given good satisfaction. It is used in connection with two separate distributions; one is controlled by this valve and connected to a stand-pipe; the other is at times required to maintain a much greater pressure for fires. The pump supplying both has a capacity of 9 000 000 gallons in twenty-four hours. This valve is used to avoid separate pumps for each distribution.

A modification of this plan requiring much less length in the machine can be substituted with equally good results, provided care is taken to avoid friction in the moving parts; as, for instance, the weights may be below or around the water cylinder.

Plate XXX shows an air-vessel on the suction-pipe of the pumps of the Argentine Water and Electric Works Company, at Argentine, Kansas. Before this was applied the pumps drawing from the tube wells received so large a supply of air as to make them work with a hammering action. The air is caught in this air-vessel and drawn off by the tube at (*E*) leading to the jet-condenser. This tube is placed below the top to retain some air in the air-vessel to prevent water-hammer on the suction-pipe.

Plates XXXI and XXXII show an arrangement for collecting air from a suction-pipe 3 miles long. The water coming in at *C* is permitted to part with its air as it flows through the large pipe *A*, and thus the air passes upward into a horizontal air-vessel provided with a float *D*. This operates a whistle-valve and a rope to work a throttle-valve, so that the engineer will be notified and the pumping-engine cared for, before the flow of air reaches the pump. A pipe (*X*) is provided to draw off the excess of air to a jet-condenser. In cases where a surface-condenser is used the excess of air has to be taken off without allowing any water to escape.

The trap (Plates XXXIII and XXXIV) has been designed and is

used by the writer with success. The top bonnet *D* is secured over the escape, and the pipe at *A* leads to the surface-condenser. This arrangement of air-trap has worked well.

It will be noticed that the valve is small, while the float or power to work it is comparatively much larger than has generally been used; this is done to ensure uniform certainty in operation. A strap valve is shown on top to keep out dust or back flow of air. The bonnet *D* need not be used when discharging into the open air.

The new devices described in this communication are hereby surrendered to the public.

Mr. Sickels desires to state that the print copies of these valves, etc., can be obtained on application and payment of cost.

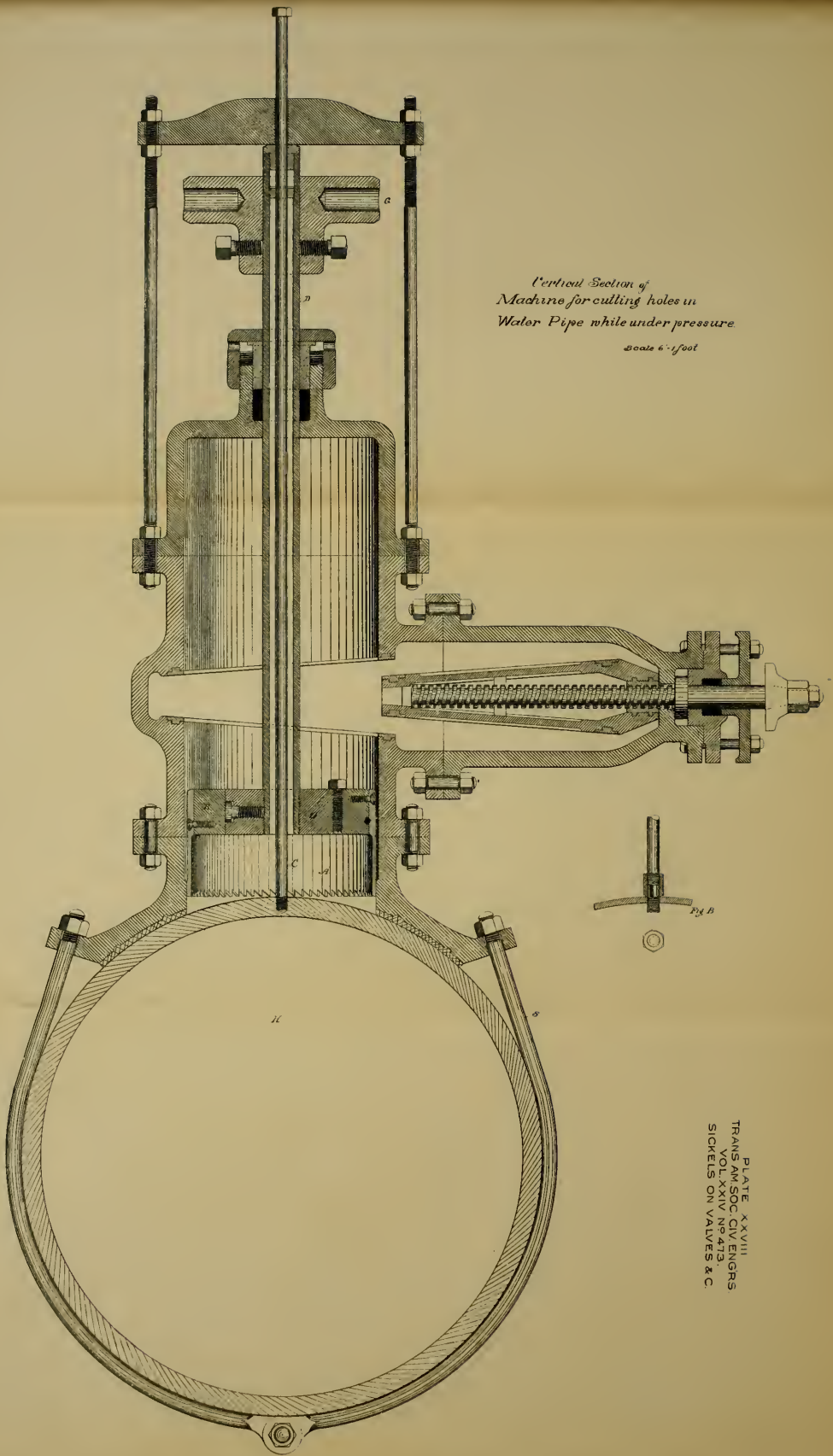


PLATE XXVIII
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXIV No. 473.
SICKELS ON VALVES &c.

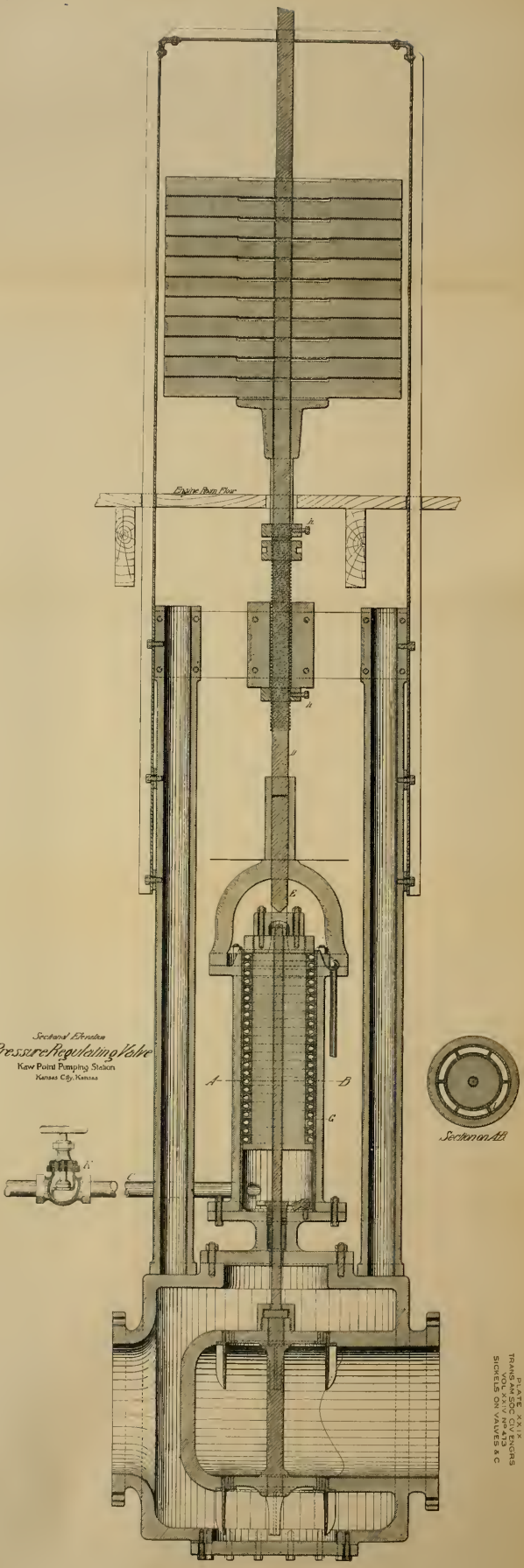
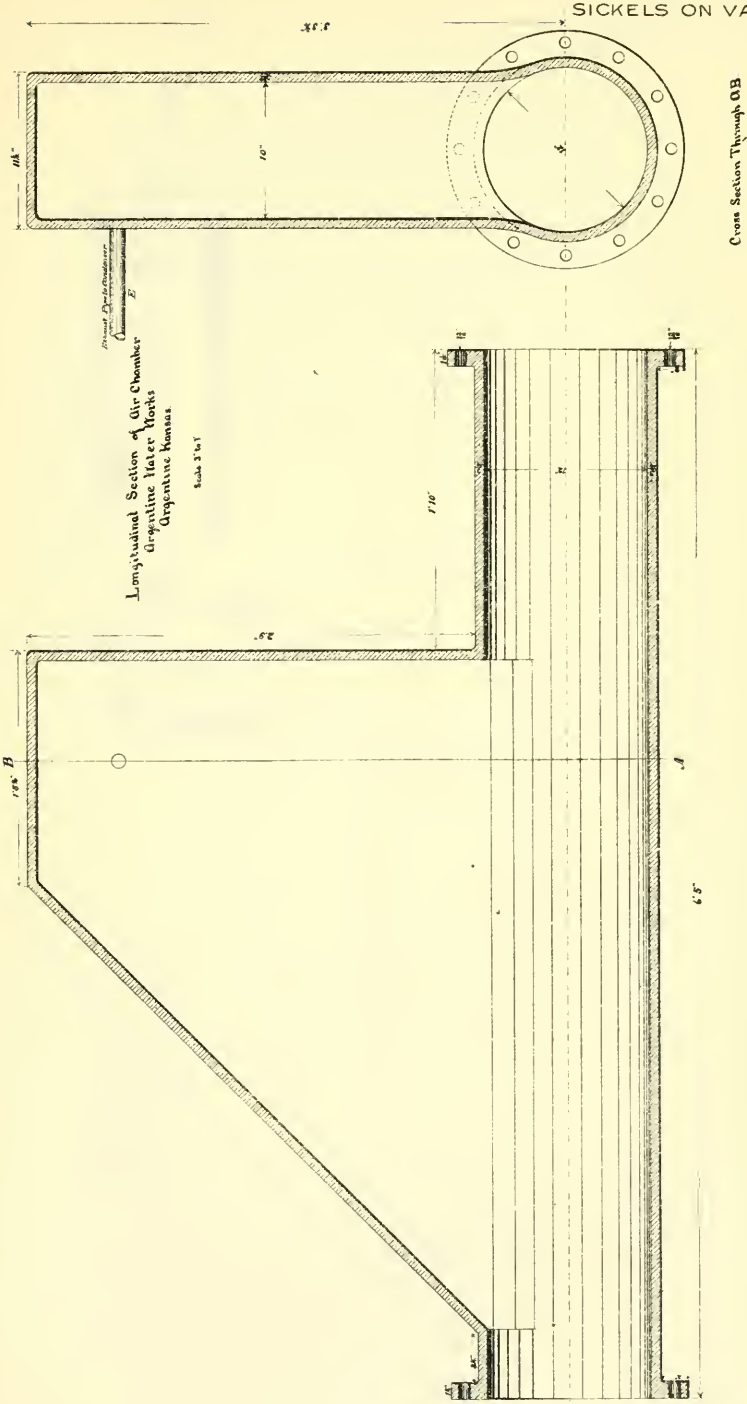
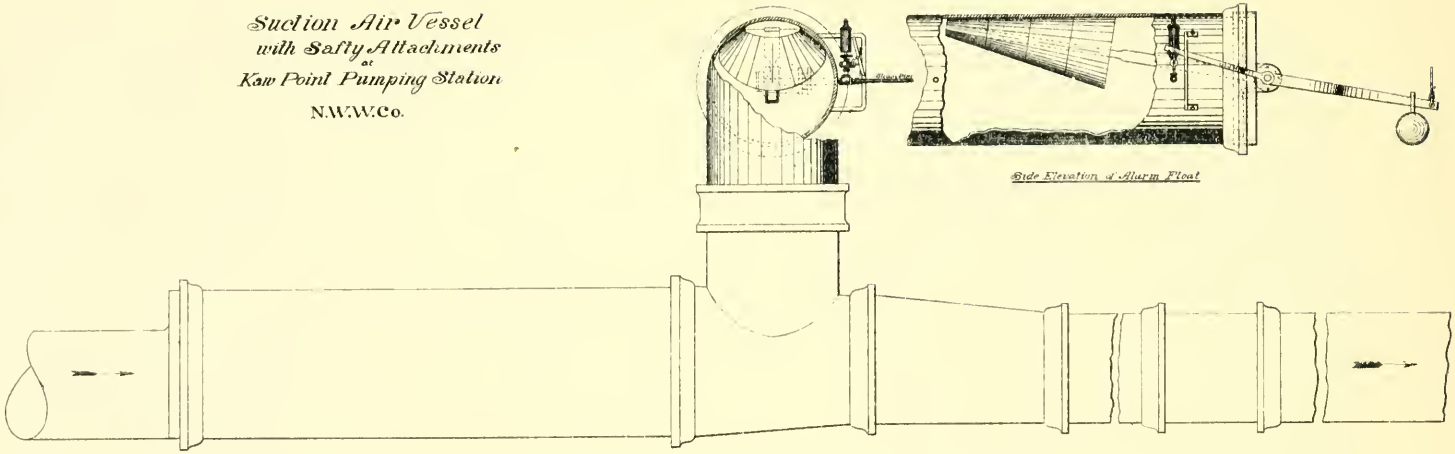


PLATE XXIX
TRANS. AM. SOC. CIV. ENGRS
KANSAS CITY WATER WORKS
SICKELS ON VALVES &c

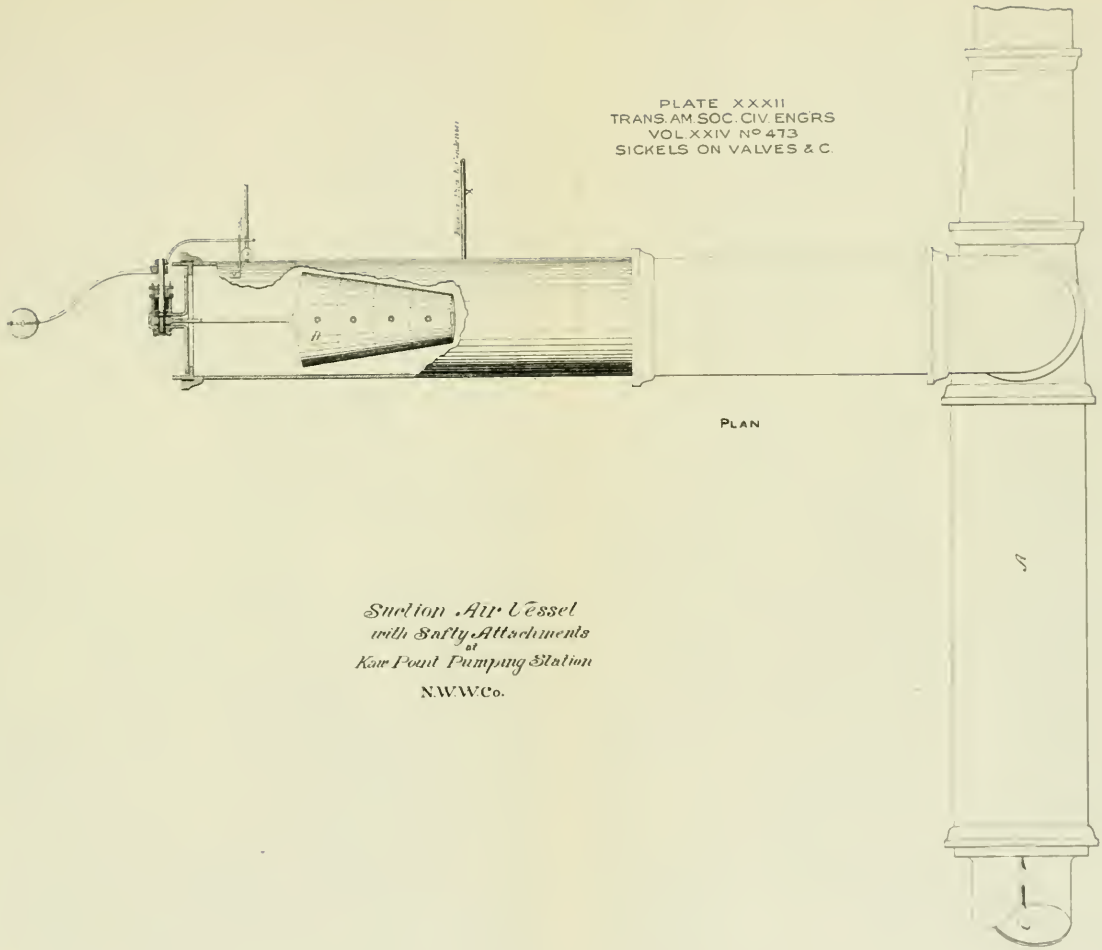

Longitudinal Section of Air Chamber
Argentine Water Works
Argentine Kansas.
Scale 3" to 1'
Cross Section Through O.B
B
A
O

Suction Air Vessel
with Safty Attachments
at
Kaw Point Pumping Station
N.W.W.Co.

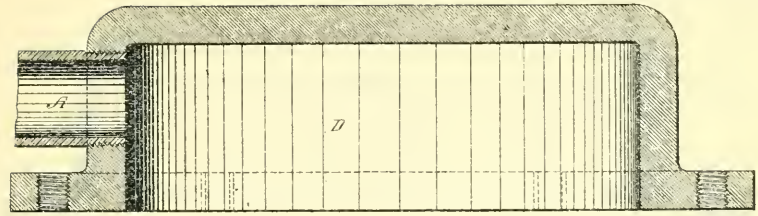


END ELEVATION.

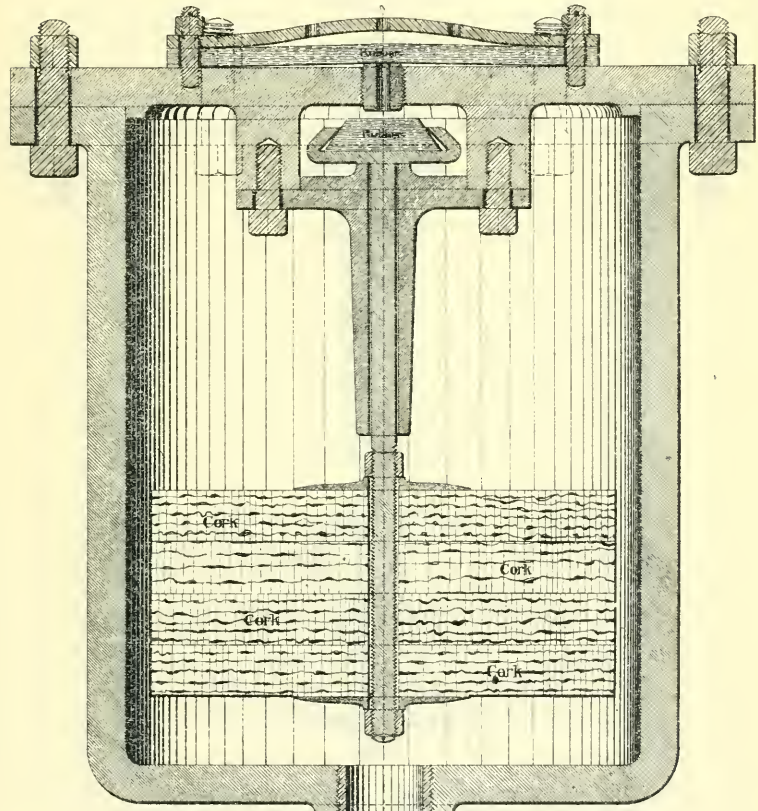
PLATE XXXII
TRANS. AM. SOC. CIV. ENG'RS
VOL. XXIV No. 473
SICKELS ON VALVES & C.



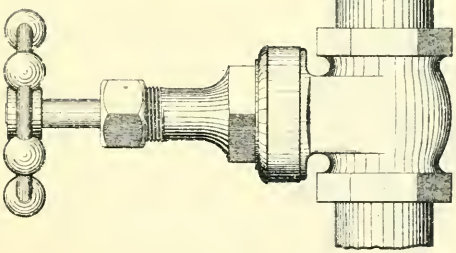
Suction Air Vessel
with Safty Attachments
at
Kaw Point Pumping Station
N.W.W.Co.



Section of Barrel

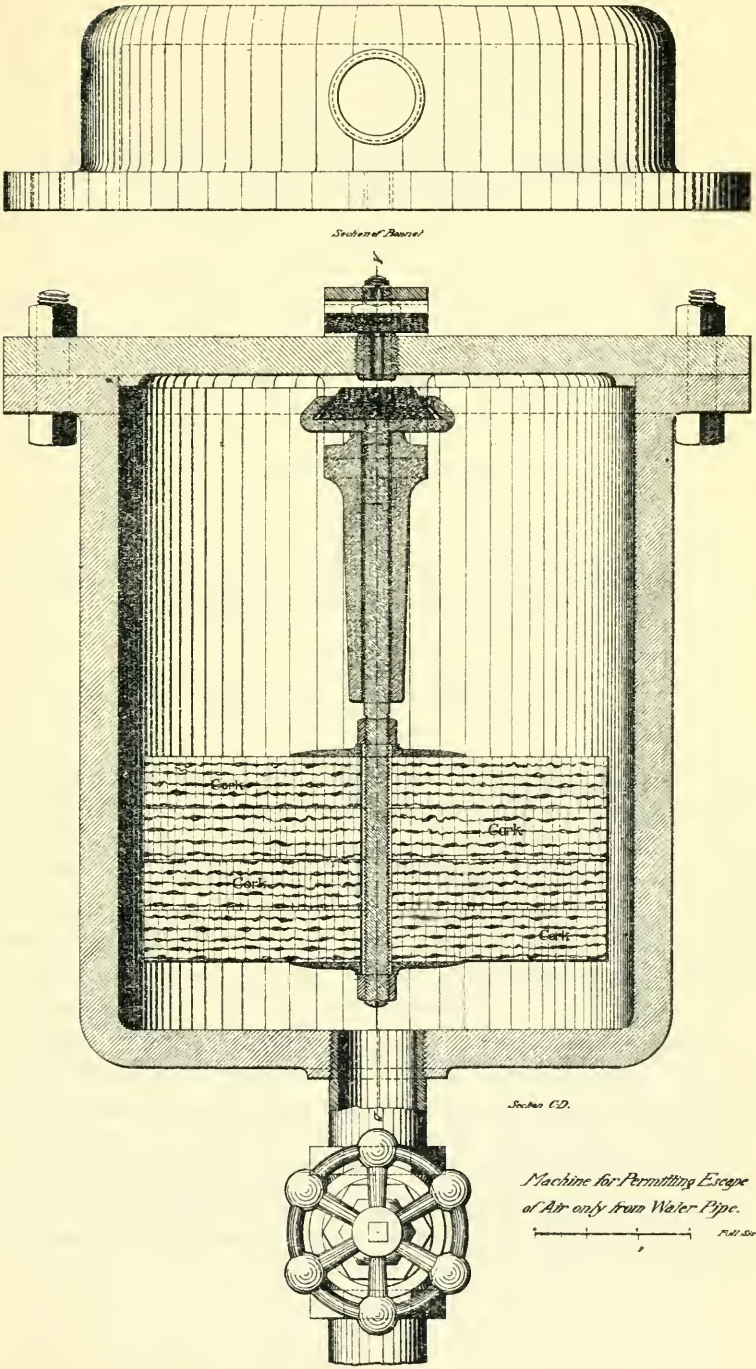


Section AB.



Machine for Permitting Escape of Air only from Water Pipe.

Full Size.


Section of Barrel
Cork
Cork
Cork
Cork
Section CD.
Machine for Permitting Escape
of Air only from Water Pipe.
Full Size.

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474.
(Vol. XXIV.—May, 1891.)

THE COLORADO AUTOMATIC REFRIGERATOR SYSTEM AT DENVER, COLO.

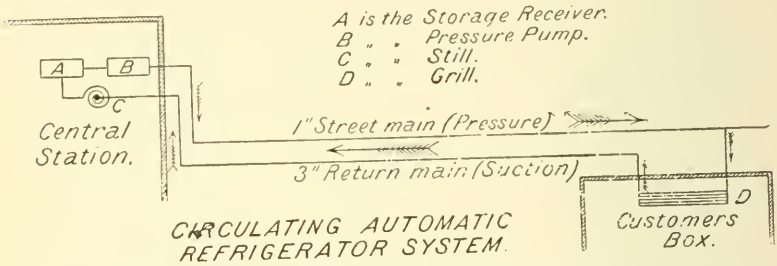
By A. McL. HAWKS, Jun. Am. Soc. C. E.

An interesting and commercially successful experiment in furnishing a refrigerating medium through a main, in the same manner as steam, gas or water is supplied, has been going on in Denver, Colo., for nearly two years. As the enterprise has proven of merit, and is likely to be adopted in nearly all large cities, and, as information on the subject is hard to be obtained, I furnish a brief from a report which I made to the City Counselor of St. Louis, where a similar company had applied for a franchise to lay mains through the streets.

Originally, freezing machines were made for obtaining ice, and providing customers with this product. After that the aim was to furnish the refrigerant to a cold storage warehouse adjacent to the ice machine, and from there the step was easy to supplying any refrigerator along a line of mains. In these machines all liquids which readily evaporate have been experimented with. Since the days of Carré, ammonia has been accepted as the best, because of its affinity for water, and because it

is non-explosive, non-inflammable, and by its odor gives immediate warning of any leak or damage. Ammoniacal liquor of the proportion 29 parts pure ammonia to 71 parts water has been determined by many experiments to be the cheapest and most efficient.

The process consists, essentially, in the forcing of this liquor through the main to the point where refrigeration is desired; the sudden increase of space at that point, so it may quickly vaporize, and the absorption by water, to return on a suction line to the central station;



CIRCULATING AUTOMATIC REFRIGERATOR SYSTEM.

the redistillation of the ammonia, and the removal of heat during this process. So that the system is practically automatic and once charged is run continuously, and, barring accidents, without loss.

In March, 1889, the company installed the plant, consisting of one 30-ton ice machine, about 2 miles of mains (with connections for twenty-nine boxes having an air space of 70 000 cubic feet), and the cold storeage warehouse of 50 000 cubic feet capacity. The main is one of the striking featnres of the plant. It is a 1-inch wrought-iron pipe and is not only capable of caring for the 70 000 cubic feet of air space now in use, but, by the installation of another 30-ton machine, can care for 150 000 cubic feet. The valves in the box connections have a clear opening of $\frac{1}{64}$th of an inch, which will serve for any ordinary cold storage room. Beyond these valves is an inch connection with a grill of $1\frac{1}{2}$-inch pipes on the ceiling of the room, at the far end of which is a $1\frac{1}{2}$-inch return pipe to the 3-inch main leading back to the central station.

As the work was entirely in the line of an experiment the cheapest and most convenient materials were used. The conduit is a box about 20 inches square, made of rough planks, and encloses the 1-inch main, the 3-inch return, box connections, and electric wires for detection of leaks or any disarrangement of the plant. The box is divided into sections, and each section has pipes coming to the surface of the ground at

the curbline of the street. By means of these "smelling pipes" a leak or break can be traced up to the section, and then to the very connection which is at fault. An improvement in the conduit, which will be adopted in all future work, is the use of vitrified clay instead of wood. All the specials, as originally put in, were enclosed in larger specials of cast-iron, and the space securely packed with rubber. As the slightest leak of the ammonia turned the packing into "sponge rubber," which exerted an expansive pressure sufficient to burst these cast specials, new designs of wrought-iron were adopted, and all cast-iron fixtures were taken off. With the exception of these and a few minor details, no changes have been necessary, and in no case has any customer been cut off for more than three hours, and not a single loss or damage has been caused by this company. The electric connections through the conduit, to notify the central station of breaks, are not quite perfected, nor are the electric valves at the boxes for automatically regulating the temperature in each box, a thorough success; due, probably, more to the diminutive size of the opening ($\frac{1}{64}$th of an inch) than to any defect in the principle.

A patrol regulates these things at present, but it is expected soon that the defects will be regulated and the plant will become thoroughly automatic. The main features, however, have been demonstrated to be thoroughly practicable, and no great changes will be made in them.

In May, 1889, the first customers were connected with the mains, and tests were made to show the advantages of the system. Two similar boxes, with similar contents for preservation, the one fitted for ammonia freezing, the other one-third filled with ice, were tested by thermometers placed in various parts. After about eight hours, the ice had reduced the temperature from about 62 to 47 degrees Fahr.; after nearly two days to 41 degrees Fahr., and that seemed to be the limit. But by the ammonia process it could be lowered to 40 degrees Fahr., or even lower in less than fifteen minutes; the air in this case was dry and pure (all moisture collecting at once on the grill overhead in the form of frost) instead of damp and moist; and meats, fish, etc., once frozen, remain so during the whole period of storage. In one case a piece of meat was kept six months and then cooked and eaten, and the difference in flavor between it and fresh meat, could not be detected. As soon as business was commenced a problem was met in the regulation of prices. Old ice bills were consulted, and a basis of so much per cubic foot of air space in the

box was decided upon. But in some cases this was so manifestly unjust that an arbitrary price was agreed upon. Later researches, based on steam-heating calculations, show a surprising agreement with the old ice bills, and what seemed impossible on the former basis, is shown to be very reasonable. So all new contracts are made on the later schedule of exposed surface and openings.

All customers express themselves as very well pleased with the system and its results. The third of their box formerly devoted to ice is a clear gain, as the grill overhead occupies no space that is ever used. The temperature, instead of being a varying quantity, dependent upon the arrival of the iceman, and never below 40 degrees Fahr., can be reduced to any degree above 25 degrees Fahr. in a few minutes, and maintained within 2 degrees Fahr. of the same. Instead of the usual moist, disagreeable air of an ice refrigerator, it is dry, sweet and clean; and the opening of a valve takes the place of the iceman's visit—with all uncomfortable circumstances. So enthusiastic over it are some customers that I cannot refrain from quoting two extracts. One consumer says: "The Colorado Automatic Refrigerating Company's system is absolutely perfect, and is something that a butcher needs to use for only one week to make him feel that he is rescued from one of the greatest evils of the butcher's business, namely, the price, trouble, labor, and dirt, attendant upon handling natural ice;" and another writes: "To-day, if ice was given me gratis, and even placed in my box free of charge, I would not use it, and exchange my present method of obtaining cold air." These go to show the way the system is regarded by all who know it thoroughly, and that it has passed through the experimental stage to a well settled business enterprise.

NOTE.—William J. Haskins, M. Am. Soc. C. E., discussed the paper briefly, but asks that his remarks be omitted, as he proposes to present them in the form of a paper.

It is understood that some of the leading features in this plant are subject to patents.

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475.
(Vol. XXIV.—May, 1891.)

CONCRETE SEWER AT MT. VERNON.

By WILLIAM E. WORTHEN, Past President Am. Soc. C. E.

WITH DISCUSSION.

In laying out the main outlet sewer at Mt. Vernon, N. Y., it was found that a large portion of the line must be excavated through rock, and I decided that for economical reasons the sewer should consist of a concrete channel, constructed in situ, with an arch covering in stone. In this way all the rock saved from the trench was valuable for the macadamizing of streets, no earth was necessary for filling over the arch, which would have been needed if cement or vitrified sewer pipe had been laid, and this earth involved long haul. In addition, such a cross-section could be secured that a man could readily pass through the sewer, a convenience in cleaning and a saving in the number of manholes. It was not supposed that at Mt. Vernon the sewer would be used as a subway for electric wires, gas or water pipes, but it could be readily arranged for such purposes.

Figs. 1 and 2 show sections of the sewer and the general form of construction; only the minimum of rock excavation was required, sufficient in all cases to give a few inches in thickness of concrete. The invert is a section of vitrified pipe, such as is sold for such purposes; this is bedded in cement mortar on the rock or on concrete to a true line and grade, on this is placed the invert center, Fig. 1, and concrete of Rosendale cement (mixed 1 cement, 2 sand and 4 of broken rock not larger than 2 inches) is rammed around its sides. After the concrete has set, the invert center is removed and the face of the cement is struck with a thin coat, say ¼-inch thick of Portland cement well troweled on, a plumb ⊥, Fig. 2, of which the base fits the opening of the channel, is

placed within it so as to be central and vertical. In this plumb are a number of holes, which are centers for describing the arch, and the centers used are those best suited to the rock excavation. In this case the radius of the arch was invariably two feet, and this radius either by a string or rod was applied at different centers, till one was found best adapted to the rock cut. In general the arches were laid horizontal and the same center in the plumb used for a convenient length or section; after that another center might be taken with a vertical offset, but if more convenient, the arches might be laid on an incline, so that in some places the sewer would be 6 feet to 7 feet high. The practice was to arrange for the skewbacks first and then set the usual centers of about 3 feet wide and complete the arch from stone from 10 inches thick and upward, taken from the cut and laid in cement. The upper surface of the arch was kept as high as the rock cut and the proper depth below the grade of the street would admit.

This construction applied only to the main outlet sewer, in which there was no spur for house connections, all the other sewers were of vitrified pipe of various diameters from 8 to 18 inches, the minimum being 8 inches. All the house connections were 6 inches in diameter. By the provisions of the contract there was to be a capped ⊥ pipe next to the bend from the spur. The idea was to obtain ready access for the removal of obstacles in either the main sewer or its branches. To simplify this the bend, Fig. 3, was adopted, which was the first connection with the spur on the main line. The oblong hole gives a ready and short reach to both the main line and to the house connections. After the cover is put on with earth packing, the trench is filled in and access can be got only by digging down. The usual depth of mains is 9 feet to invert, and the distances between spurs, 25 feet on each side.

In manholes where the lateral sewer came in on a level considerably above that of the main sewer, I put a ⊢ on the line of the lateral and just inside of the wall of the manhole with the upper end open, so that the flow of the lateral was readily seen, and the other end was extended down with an elbow at the bottom to the level of the main sewer.

DISCUSSION.

Mr. Worthen.—In answer to Mr. Brush as to the cost. All the work was done by contract, generally so much per lineal foot, including rock excavation and sewer; in some places, rock excavation by the cubic

yard and the sewer by the lineal foot; occasionally in short lengths there was no rock, then a rough rubble wall was laid, which was faced with concrete the same as in rock. The price given for the work would afford but little criterion of its cost, but I was satisfied that under the same conditions and on economical considerations, I should adopt similar construction.

In answer to Mr. Harris with regard to manholes. There are manholes invariably in all sewers, except the outlet, at every street junction, at every change of grade and intermediate at about 500 feet apart, the special hand hole bends at each spur are to remove obstruction in the main between manholes and in the house connections.

In answer to J. Foster Crowell as to thickness of concrete. I preferred that there should be no concrete at the bottom, but to bed the vitrified invert cement directly on the rock. At the sides the minimum thickness would be about 3 inches, space enough to pack the concrete merely. The Portland cement plaster was from $\frac{1}{16}$ to $\frac{1}{4}$ inch thick, and perhaps sometimes more, to bring the surface smooth and even. Cement laid on with a brush will resist the passage of water. It is not the thickness, but the thorough working which makes cement impervious.

J. Foster Crowell, M. Am. Soc. C. E.—The use of concrete in the form which Mr. Worthen has described to us, points to the general possibilities of this material; in the United States we still use it sparingly, although its range of application is continually widening.

I was in the Island of Jamaica a few months ago, where there is very little, if any, good building stone, and concrete is used to a very large extent.

The Jamaica Railway Company were then building an extension of their line, and I was invited to examine the works. Away up in the mountains they were building concrete pipe-culverts, of 4 feet diameter and over, and they were doing it in a very successful way. I was much interested to see how easy it was to do what with us at home has generally been considered not feasible; here, when we use pipe-culverts for railroad work, we usually employ extra heavy earthen sewer-pipe or cast-iron pipe, either of which is costly, and often difficult of transportation, but there they were easily and swiftly building the culverts right at the site; they had a portable platform which could be brought quite near, on which were ranged a number of spacing-blocks conforming to the circumferences of the inner and outer frames of cylindrical wooden moulds; the frames were placed vertically on the platform, secured firmly at the bottom by the spacing-blocks, and clamped together at the top, the proper gauge being maintained by double wedges between the two halves of the inner frame; the concrete, composed of cement, sand and gravel, was poured in and rammed; after sufficient time had been allowed, the wedges were removed, and the inner frame taken out, just as centers are struck, and then the outer frame could be

lifted off. The same platform could of course be used for various sizes and several sections of pipe at one time, and could readily be moved along from place to place; although the whole operation was being performed by negro laborers, there was nothing wanting either in strength or smoothness of the finished pipes. If I remember correctly, they had a rough rule of 1 inch thickness of pipe for each foot of diameter. The ease and cheapness with which the cement can be transported, compared with manufactured pipe, would recommend this form of construction, even if the actual first cost of material also was not less; in this case the chief cost was in the cement, sand and gravel being generally found close at hand.

I was also shown a very heavy retaining-wall, 20 feet or more in height, on the concave side of a sharp bend of the River Cobra, built to support the railway embankment where exposed to the full effect of formidable freshets; the wall was entirely of concrete from toe to coping, and had been in service for several seasons with absolute perfection.

Concrete is used in Kingston for architectural purposes to an extent we do not dream of here. They use it for arches, retaining-walls, colonnades, the walls of houses, stairways, of which the entire structure of supporting members and treads is a homogeneous body of fine concrete, and, generally speaking, wherever we would use stone; the quality is very strong, hard and enduring.

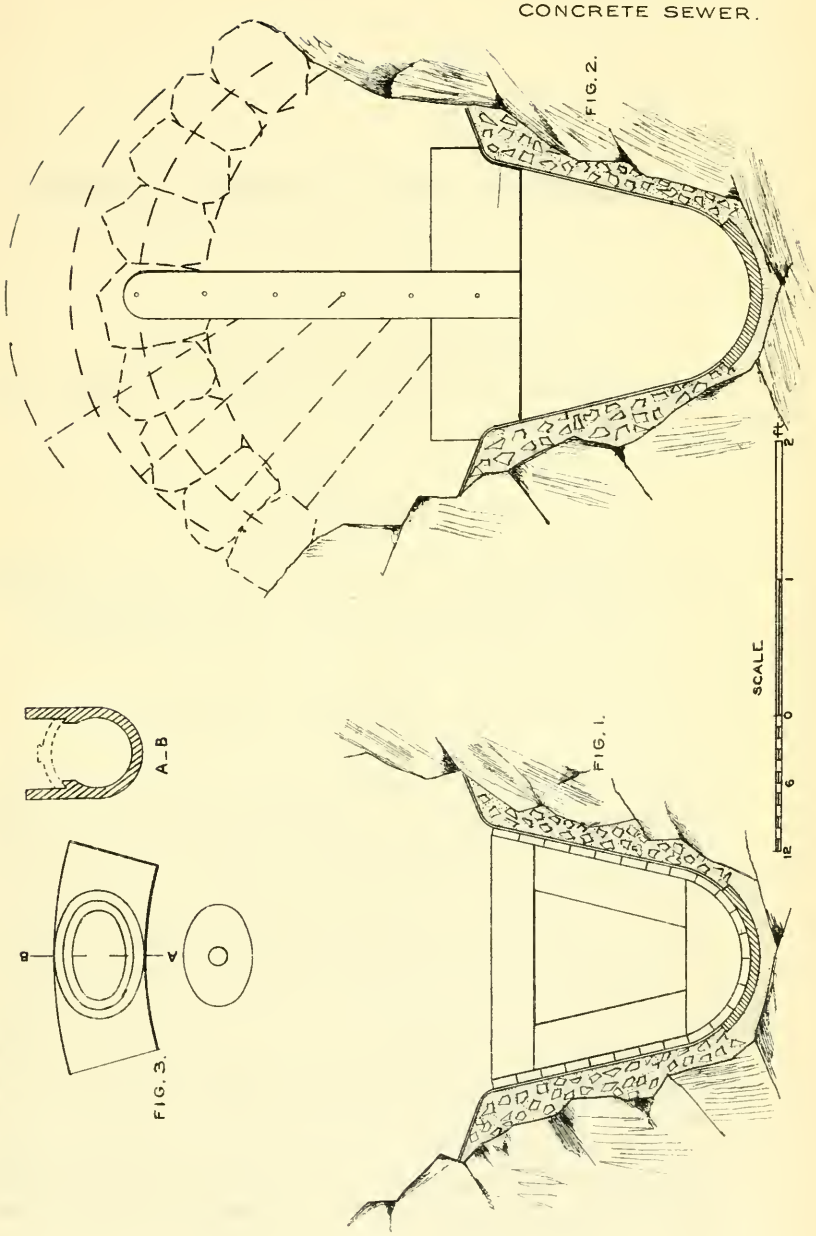
Horace Andrews, M. Am. Soc. C. E.—I should like to inquire as to the concrete used by Mr. Worthen in the Mt. Vernon sewers. Was the cement used Portland? I should apprehend failure of the concrete unless it was of better construction and of better material than is usually secured with natural (or Rosendale) cement in work of this character.*

Lamp-holes at the ends of lateral sewers, or at changes of grade between manholes, are of considerable use for flushing purposes, and to enable the superintendent of sewers to quickly decide as to the nature of stoppages claimed to exist in the sewer, and which, by the use of these appurtenances, may be shown to be in the house-drain and not in the sewer. I do not quite understand whether Mr. Worthen means that a ⊥ opening upward at each house connection was made on the same length of pipe as that provided with the usual Y for the house connection, or that a ⊥ branch immediately followed the 2 feet length of pipe with Y moulded on for house connection. If the latter supposition is correct, the expense of such construction would exceed that of an occasional lamp-hole, while in no case will the ⊥ openings be as useful as occasional man or lamp-holes.

The method mentioned of bringing the laterals into the manholes will preclude the use of rods for removing obstructions in the laterals, and it will also prevent flushing balls from being passed from manhole to manhole.

* Mr. Worthen, subsequently to its reading, inserted the reply to this query in the paper.

PLATE XXXV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXIV. No 475.
WORTHEN ON
CONCRETE SEWER.



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(Vol. XXIV.—May, 1891.)

ADDRESS AT THE ANNUAL CONVENTION AT CHATTANOOGA, TENN., MAY 22D, 1891.

By O. CHANUTE, President Am. Soc. C. E.

The field of engineering has now grown so large and is being cultivated in so many different directions, that it is scarcely practicable for the member who has been honored by election to the Presidency of this Society, to review in the annual address the engineering advance in all of these different directions, for an attempt to do so would probably result in a dry catalogue, chiefly consisting of numerical data. In fact, having gathered a good deal more information than I can make interesting within the time at my command, I shall not undertake upon this occasion to present to you a review of the whole field, and the members present will thereby be spared a good many indigestible statistics which I have collected; but I shall endeavor instead to select a few of the leading engineering works of the past year, to touch upon the new things and the advance which they indicate upon previous practice, and to interest you with an account of some engineering proposals which seem to possess features of novelty.

Tunnels.

The principal engineering achievements during the past year have been in connection with tunnels. First, there was the completion of the new Croton Aqueduct, practically a rock tunnel 30 miles long, under charge of Mr. A. Fteley, Vice-President of this Society, which was opened on the 15th of July, 1890, having taken five years in boring. Its full capacity is 318 000 000 gallons per day, and its cost to June 30th, 1890, was $23 561 973. Next there was the successful driving through of the railroad tunnel beneath the St. Clair River at Sarnia, under charge of Mr. Joseph Hobson, Member of this Society; an achievement which seems likely to inaugurate a period of considerable activity in similar works in this country. You will remember that tunnels under rivers have hitherto been believed to involve almost insuperable difficulties, that a similar work was abandoned at Detroit some seventeen years ago, after considerable sums had been spent on trial headings, under one of our ablest engineers, Mr. Chesbrough, that work was also suspended upon the Hudson River tunnel at New York in 1887, because capitalists had lost faith in its successful completion, and that a good many important crossings of rivers have remained in abeyance, halting between the opposition of the marine interests to a bridge, and the difficulties which were thought to be involved in an attempt to tunnel. These difficulties seem to have been so far resolved in the Sarnia and other recent tunnels, that we may expect capital to be furnished freely for analogous projects in the near future.

The tunnel under the St. Clair River at Sarnia was built for the Grand Trunk Railway by the St. Clair Tunnel Company of Canada. It is for a single track, and just 6 000 feet long between portals; 2 290 feet of this distance being under the river proper. It is driven through soft blue and gray clays, with occasional pockets of gravel and quicksand. Casual boulders were met with, while inflammable and explosive gas, issuing through fissures, added much to the danger of carrying on the work. The success achieved was chiefly due to improvements in the shield, which latter was designed by Mr. Hobson; to the rapidity with which the lining could be put in place; and to the admirable organization of the work and plant. The shield was cylindrical in form, 21 feet 6 inches in diameter, 15 feet 3 inches long, and built of 1-inch steel plates. It was forced forward 18½ inches at a time by 24 hydraulic rams distributed around the circumference at the back of the shield, and taking their

bearing against the completed portion of the lining. Their aggregate capacity was 3 000 tons as a maximum. The front portion of the shield is divided into twelve compartments or pockets, which form shelves upon which men stand to excavate the material in front of them, under cover of the cutting edge. This material is passed back through two doors in the lower portion of the shield, which can be rapidly closed, should the men be driven away from the front by the intrusion of soft or liquid material. After passing through those doors, the excavated material is conveyed to a dump, upon small cars running over a service track. The work was carried on night and day from each end, and was performed at normal air pressures, that is to say, with the outer ends of the tunnel open, until the edges of the river were reached. Then bulkheads were put in at these points, and the remainder was excavated in compressed air, with pressures varying from 10 to 28 pounds to the square inch, in order to keep back the intrusion of water by drying the exposed surfaces of the clay, and to support the latter to a certain extent, by increasing the air resistance.

The lining is of cast-iron, 2 inches thick. The ring is 21 feet in outside diameter, and divided into thirteen segments, each 4 feet $11\frac{15}{16}$ inches long, provided with flanges by which they are bolted together. Thin packing pieces of seasoned oak are inserted between the segments, which by their swelling, when in contact with moisture, produce a water-tight joint. Lengthways of the tunnel each lining ring measures $18\frac{1}{4}$ inches, and the segments are swung into place by a rotating arm or crane, which can be extended and has also a radial motion. Less than one hour sufficed to swing and bolt into place a ring of segments, and it has been done in forty-five minutes, the clay being kept back meanwhile by the projecting hood or rim, 4 feet long, at the back of the shield. When at the next forward movement this rim is slid forward, the annular space, 1 inch thick, thus left, was filled by injecting cement grout to prevent caving. The shield was controlled and kept in true line by bringing less or more of the rams into action. They were all independent of each other, and by working each of the twenty-four rams as required, the direction of the shield could be altered at pleasure. This feature proved a complete success, the work never varied more than 2 inches out of true position, and at the final outcome the two shields met exactly, under the river, both as to line and to level.

The works were lighted by electric incandescent lights and drained

by pumping engines, but the precautions taken were so complete that there was very little water to take care of. As may be imagined, such an extensive and care-compelling piece of work required a good deal of machinery. This was admirably arranged, chiefly in groups at each end of the tunnel, and a visit to the plant conveyed more the impression of a well organized manufacturing establishment than that of an ordinary tunnel outfit, generally bristling with temporary expedients. There was a place for everything and everything was in its place, while every man understood clearly his duty and performed it promptly.

Excavation began in January, 1889, and the tunnel proper was started July 1st, 1889, on the American side, and September 21st, 1889, on the Canadian side. The two shields met on the 30th of August, 1890, thus practically occupying one year to go 6 000 feet, or at the average rate of about 8 feet per day per heading. Meanwhile, work was resumed upon a very similar plan upon the tunnel under the Hudson River at New York. The shield was designed and constructed in England, and is practically upon the "Greathead" system, which will be further alluded to hereafter. The work is now in progress, and is said to be advancing at the rate of 10 or 12 feet per day through the Hudson River silt which proved so troublesome during the previous occasion. It is understood that it has practically been decided to build a similar tunnel under the river at Detroit, in lieu of the bridge, for which a charter has been sought for during the past few years; that in fact the work has been begun so as to hold the charter, and that it is expected to complete the tunnel within two years.

Antedating somewhat the Sarnia tunnel, a similar work upon a similar system, consisting of the subway tunnels for the "City and South London Railway," has been carried on in London, on the designs and under the supervision of Mr. J. N. Greathead, C. E. This work extends from the "Monument," close to London Bridge, under the Thames, to a point on the Clapham Road near Stockwell, a distance of some 3¼ miles, and was opened to the public on the 4th of November, 1890. The subway is sunk some 50 or 60 feet below the surface, thus avoiding all interference with sewers, gas and water pipes, foundations of buildings, etc., and therefore reducing very greatly the land and other damages which have proved so expensive in such city works. It consists of two separate tunnels, each 10 feet in diameter, driven through the London clay by the methods devised by Mr. Greathead. These mainly consist in

forcing forward a metallic shield by hydraulic power, as fast as the material is excavated ahead, and lining up behind with built-up rings of cast-iron plates, much in the way which has been described in treating of the Sarnia tunnel. The diameter being small, a forward progress of 16 feet per day was frequently obtained, and the two tunnels were kept entirely separate from each other, being generally side by side, but in some cases being one above the other. This division into separate subways, not only reduces the amount of excavation, but it confines each train within its own tunnel, thus limiting its possible wreck if it leaves the track, and avoiding the danger of its being run into by a train running upon the other track; it also greatly improves the ventilation of this underground railway by causing each train to act as a piston and to drive out the air ahead of it.

The railway carriages are cylindrical in form, and are hauled by electric locomotives, thus suppressing the foul gases which have proved so annoying in the London underground railways now worked by steam locomotives. Inasmuch as passengers are conveyed between the street and the underground stations by elevators, the increased depth is not objectionable, and the line is actually found to be more accessible than the Metropolitan Railway, which is only half as deep, but is reached by staircases. The electric machinery is said to be working well, and the line to be meeting with much public favor, so much so that already a considerable number of similar projects are in the field. It is proposed to provide deep subway lines for London and for New York; and a triple tunnel line for carriages and foot passengers is now in progress under the Clyde, at Glasgow.

Still another system of tunneling has been introduced in England during the past summer, in boring a tunnel 1 560 feet long and 25 to 26 feet in diameter, for an additional double-track railway line at King's Cross Station, in London. This system is that of Jennings & Stannard, patentees, and consists in supporting the clay while driving through it, upon iron or steel sheet piles or needles 10 feet 6 inches long, 12 inches wide and 2 inches thick, so tongued and grooved as to interlock each other, while permitting of sliding forward. These needles are driven forward into the clay, from one to three at a time, by hydraulic jacks, until but one or two feet rest upon the brick-work of the finished portion. The other end is supported upon timbering, as the excavation and brick lining progresses, and the needles having a cutting edge, shape the

excavation to the desired section. As they are but 2 inches thick, no subsidence is said to take place upon their being driven forward after the lining is built, inasmuch as the thickness occupied by them is filled up with cement grouting, through tubes provided for that purpose, as fast as the work progresses. This method evidently requires but an inexpensive plant, and readily admits of changes in the size and shape of the excavation. It is not unlikely that in firm clay it may prove cheaper and more expeditious than the working with a shield, but in treacherous material, the latter would seem to be much safer and more reliable.

Reference may be made, while touching on tunnel materials, to the drainage tunnel for the Valley of Mexico, 9.76 miles long, which is now being driven through the "tepetate" of that country, and which is expected to be completed in 1892. This "tepetate" is a sort of volcanic mud thoroughly compacted, which cuts like half-baked clay, and stands a good deal like rock until it is attacked by water and weather. It was through this material, that Martinez, the Mexican engineer, performed in 1608 the extraordinary feat of driving a drainage tunnel more than 4 miles long in eleven months, with impressed Indian laborers and the crudest mechanical appliances. Some of you, at least, will remember that our fellow member Mr. De Garay gave us in 1882, a most interesting account of this great work; which led, when the unlined tunnel caved and choked up, to the digging of the "Nochistongo" cut, the greatest in the world, occupying one hundred and fifty years in its monstrous excavation; and how he explained the reasons which required the boring of a new tunnel in connection with an adequate drainage canal. These works are now in progress, the tunnel excavation being supported by the old-fashioned timbering methods, which are said to answer well in this good ground.

The various tunneling methods which have so far been described, are applicable chiefly to clay or firm silt, and it is notable that through this class of material the progress has generally been from 10 to 13 feet per day, no matter what was the size of the excavation or the system employed. In solid rock or in soft and porous materials, some other methods are preferable, and may be briefly touched upon. For soft rock, like chalk, remarkable results have been achieved with a machine invented by Colonels Beaumont and English, of the British Royal Engineers, in the proposed tunnel between Dover and Calais, prior to the suspension of the work some nine years ago. This machine consists

chiefly in a very massive cutter head (driven by compressed air), in the shape of a single cross arm of the diameter of the heading tunnel to be cut, say 7 to 8 feet. It is provided with cast-iron cutters, so arranged that as the edges wear they can be turned so as to present new cutting points, and it is said to bore with extraordinary rapidity. It is stated to have eaten into the chalk at the rate of a foot every ten minutes, and that upon one occasion the progress obtained on a trial was 87 feet in twenty-four hours, including the removal of the debris, or nearly seven times the best progress which has been made in clay.

It is, by the way, a fact but little known that this tunnel between England and France, which, if ever completed, is to be 20 miles long, has had a good deal of work done upon it. Not less than a mile is already bored at each end, and indeed it was whispered to some of the American Engineers when in Paris in 1889, that a good deal more than one mile was bored on the French side; but in any event the confidence of capitalists seems to be so great in the profitable prospects of the proposed investment, at the estimated cost of $20 000 000, that they are said to be prepared to resume operations at once, if only the military objections on the part of the British government be removed. How far the machine which has been above alluded to would be applicable to hard rock, might be well worth the experiment.

For soft, permeable and sandy soils, still other methods of tunneling must be devised, especially where, in order to maintain easy gradients, it is desirable to go but little below the bottom of a stream. For such cases the proposal has repeatedly been made to put the tunnel down from the top, by sinking a series of bottomless pneumatic caissons, end to end, and connecting them afterward together. It is evident that in that case the principal difficulty is how to make the joints or connections, and a number of ingenious devices have been proposed for that purpose. The best suggestion is probably that of applying the "Poetsch freezing process," by equipping the ends of the caissons, outside of the bulkheads, with coils of iron pipes, through which some frigorific substance can be circulated, after two adjoining caissons are in place, and soil has been dumped on top of them. The expected result would be to freeze the material surrounding and intervening between the caissons, so as to permit of driving through it, and then making a permanent connection. It is believed that this method promises considerable economy, especially in those cases where it will be practicable to dredge out a trench

in advance before dropping in the caissons, as the cost of such dredging excavation would be but about one-fifth that of excavation in compressed air, or at the heading of a shield in a tunnel.

Smaller tunnels than those which have been above mentioned, are also in progress for water-works at Chicago, Milwaukee, Cleveland and St. Louis, but these have been so frequently described, that it does not seem desirable to do more than to allude to them on this occasion.

Marine.

While we have not maintained on the ocean and in the foreign carrying trade, the relative position which the United States occupied in the days of sailing vessels, and while the railroads have pretty well curtailed the business of the steamboats upon our principal rivers, yet we have continually enlarged our marine on the Great Lakes, both as to number and size of vessels, so that the commercial fleet thereon now consists of some 1 247 sailing vessels and 1 435 steam vessels, while ten years ago there were 1 408 sailing vessels and 868 steam vessels. The maximum size has been increased from 1 200 tons to 1 900 tons for sailing vessels, and from say 1 500 tons to about 3 000 tons for steam vessels. This increase in size has been brought about by the competition of the railroads, which have, by constantly reducing their rates, compelled the lake vessels to do the same, in order to hold their trade, greater economy in water transportation having been secured by increasing the size of the vessels, and by building them of metal instead of wood.

But increased tonnage of vessels requires increased draught and depth of water, and therefore a number of works have been carried on by the general government about the great lakes, which have within the past ten years increased the navigable depths from 13 to 16 feet, and which have been shown to save annually more than their entire cost to the country at large.

Many of the new steamers which with 15½ feet draught, can carry 2 500 tons, could carry 3 000 tons with the channels deepened to 20 feet. Their speed, although not as great as that of the Transatlantic passenger steamers, may be stated at 14 to 15 miles per hour. Improvements are therefore now in progress by the building of a larger canal lock at the Sault Ste. Marie, and by deepening the channels through the St. Clair flats and at the Lime Kiln crossing at the mouth of the

Detroit River, which will soon give a navigable depth of 20 feet from Duluth to Buffalo; and one of the important engineering problems of the near future is how best further to avail of the superior economy of water transportation. Three or more projects are now being contemplated and discussed by the communities surrounding the great lakes, which will be briefly outlined.

It is only when our attention is called to the subject that we realize the economy which pertains to water transportation. Mr. Corthell, Member of this Society, in a very able and carefully prepared paper recently read before the Canadian Society of Civil Engineers, states the ocean freight rate at an average of ½ mill per ton per mile, the existing lake rate at 1½ mills, and the through rail rate at 5 mills per ton per mile. Thus the lake rate is three times and the rail rate ten times that of the ocean rate. Mr. Corthell favors a ship railway 66 miles long between Lakes Huron and Ontario, and the deepening of the St. Lawrence River, including the enlargement of the several side canals, to flank the troublesome and dangerous rapids which exist at various points, so as to give a clear navigable draught of 20 feet to the ocean. He estimates the cost of this at $27 000 000, and that of the ship railway at $15 500 000 more. He also estimates that the result will be to reduce the cost of freight from Chicago to Liverpool to $3.48 per ton, as against $6.74 per ton all-rail to New York, and thence by ship to Liverpool. The rate over the ship railway is estimated at $3\frac{4}{10}$ mills per ton per mile, as against 10 mills per ton per mile on the Welland Canal.

The second project is to connect the waters of Lake Erie with those of the Ohio River by ship canal. The general assembly of Pennsylvania authorized in 1889 the appointment of a commission to determine the feasibility of the project, and to survey and lay out a route so as to estimate the cost. This commission reported last February to the General Assembly of 1891. It recommends a route, from Conneaut harbor on Lake Erie to the Ohio River at Rochester, 103 miles long, to be extended to Pittsburgh, so as to give a navigable depth of 14 feet. The prosecution of the surveys was entrusted to Mr. J. M. Goodwin, Member of this Society, and to Mr. Thomas P. Roberts, who were also members of the Pennsylvania Commission, and the route favored makes the distance from Lake Erie to Pittsburgh, $128\frac{3}{4}$ miles. The locks proposed would be 315 feet long and 45 feet wide, with 15 feet of water on the breast wall. This would afford passage for wooden, screw,

freight steamers of "full" lake model to carry 1 500 tons of cargo on 14 feet of water; and for gunboats of the *Concord* and *Yorktown* class, which are 230 feet long on the load line, with 36 feet beam and a mean draught of 14 feet. The cost of the canal is estimated at about $27 000 000.

The third project provides for navigation incidentally as it were. The City of Chicago, having for sewerage purposes, decided to reverse the current of the Chicago River, and to cause it to empty into the Mississippi tributaries instead of Lake Michigan, will, in carrying on its drainage operations, create a navigable channel to Joliet, some 37 miles, which it is expected shall be extended by the general government to the Mississippi River. The existing canal affords 6 feet depth, and the improved water way will probable be not less than 14 feet deep from Chicago to the Illinois River, and thence 10 feet, to be ultimately increased to 14 feet, to the Mississippi. The cost of the drainage proper, the portion which the City of Chicago is to perform, has been estimated at $20 000 000 to $28 000 000, and it has been expected that the work would be under way before now. Some complications have, however, recently arisen through the imperfect legislation which was obtained before sufficient time was taken to make an exhaustive engineering investigation of all the elements of the problem, and a fresh illustration is given of the adage that great haste may result in slow speed.

Ship Railways.

Whether large loaded vessels can safely be transported overland, and whether the ship railway is destined to afford transit in locations where the difficulties of the ground, or the scarcity of water do not admit of building a canal, we shall probably know better a year or two hence, when the Chignecto Ship Railway is in operation. This is now being built, as you know, across the Isthmus of Chignecto, in Nova Scotia, and will be the first ship railway ever constructed. A paper on this subject, by Mr. J. F. O'Rourke, Member of this Society, was published in the February *Transactions*. The line of the Chignecto Ship Railway is 17 miles long, and is straight throughout. It thus avoids the use of any floating deflection tables, such as were designed by Captain Eads for the Tehuantepec Ship Railway, two or three of which are proposed by Mr. Corthell for the Hurontario line. These are to be placed at the intersection of tangents, where the direction must be changed to avoid incurring great cost, and they are likely, if ever built, to cause delays and

annoyances of various kinds. They are felt to be an unsatisfactory solution, as not only troublesome and costly in themselves, but as increasing largely the cost of grading, in order not to multiply the number of these turn-tables, and the consequent loss of time.

I remember that on the profile of the proposed Tehuantepec Ship Railway there was one tremendous cut, with level ground on each side, and that Captain Eads told me that it was through an entirely isolated rocky hill, through the middle of which he felt constrained to run his line, in order to avoid putting in a deflection table, while a detour of a few hundred feet on either side would have avoided it entirely. In point of fact, as we know, nature does not lay out her work on straight lines, and flexibility is required in ship railway lines, to conform to the natural sweeps of the country. Perhaps this requirement has been met by the invention of a British engineer, Mr. William Smith, of Aberdeen, who has patented an arrangement of ship railway, which is claimed to admit of both lateral and vertical movement of the trucks carrying the ship, without communicating these motions to the vessel which is being transported. He exhibited a working model of this on a large scale at the Edinburgh Exhibition of 1890, which picked up out of the canal, boats 38 feet long and 7 feet 6-inch beam, transported them 1 200 feet overland, on gradients varying from 1 in 20 to 1 in 75, with curves of 95 feet radius, and dropped them back into the canal at another point. The loading occupied one and one-half minutes, and the unloading one minute, and two naval experts, Sir E. J. Reed, late chief constructor of the British Navy, and Mr. W. Kiniple, expressed the opinion that by this system ordinary ships can be transported overland with absolute safety and at small cost. The car or cradle which is intended to carry the ship, rests upon compound trucks, each composed of four ordinary trucks, so as to admit of motion both laterally and vertically. The cradle approximates in outline to the vessel which is to be carried, and in this cradle are placed a series of india-rubber canvas bags or tubes, of about 8 inches diameter. For large vessels these may be increased to 3 feet in diameter. They are closed at one end and open at the other, being filled with water up to about flotation level, so that the vessel is constantly water-borne, and receives none of the twists nor shocks which may be encountered by the trucks. If this device succeeds on a large scale, as well as it seems to have done in the working model, we may expect it to effect a great reduction in the cost of location for ship railways.

Railroads.

There were built in the United States, in 1890, according to the best authority, 6 344 miles of new railroads. This was less than an average of the new mileage of the preceding five years, but it was considerably more than was built that year in any other country. It left us with an aggregate of 167 741 miles, nearly one-half of which has been constructed since 1879, and amounts to nearly 44 per cent. of the total railroad mileage of the globe.

Improvements in the operation of existing railroads have during the past year fully kept pace with construction. The extension of the operating and safety appliances so fully and ably treated of by my predecessor, President W. P. Shinn, has continued; and the application of signals, of steam heating and gas lighting for passenger cars, and power brakes and automatic couplers for freight cars has progressed with an accelerating ratio. With regard to the latter, a recent issue of *Engineering News* states that companies controlling nearly 87 000 miles of railway (over one-half the total mileage of the country) and 697 000 freight cars, have adopted the Westinghouse automatic brake, and are applying it either to all new cars, or to certain classes of new cars. Over 150 000 cars, or 13 per cent. of the whole are now so equipped. Also that on the 1st of January, 1891, the total number of cars equipped with the Master Car Builders' automatic couplers was over 102 000, or nearly 9 per cent. of the freight rolling stock in the United States.

There were last year, as stated by President Shinn, 101 576 freight cars with Westinghouse air brakes, and 56 050 freight cars with Master Car Builders' couplers. You were told last year in the annual address, what had been accomplished up to that time in the way of locomotives, and you have been told at this Convention, by Mr. W. B. Parsons, of the latest novelty in this direction. The problem is, as you know, how to get increased tractive power without injuriously increasing the weight of the driving wheels. The locomotive practically started with the "Rocket," with one pair of wheels, and a weight of 4¼ tons, then, little by little, additional driving wheels were coupled on, with many failures to get them to pull together, until we reached some two or three years ago the "Decapod" type, with ten driving wheels coupled together, and a weight of 80 tons. Now the proposal is made by Mr. Shay to work an indefinite number of driving wheels by providing the locomotive with a line of shafting, gearing into the wheels, all of them being drivers.

The heaviest locomotive thus far built upon this type is of 80 tons weight. A similar increase has within the last decade taken place in the carrying capacity of freight cars. Ten years ago the 10-ton box car was the standard, and it weighed 9 tons, or nearly as much as the useful load. Now the standard may be said to be the 20-ton car, weighing 12 tons, or six-tenths of the load, while cars of 25 or 30 tons capacity are not uncommon, the latter weighing 13 to 15 tons. It may be questioned, however, whether we are not in danger of going too far in this direction, and losing by the increased wear of rails, what we are saving in the hauling expenses. We used to think that weights on driving wheels should be limited to 12 000 pounds, and on freight car wheels to 8 000 pounds. Experiment showed some years ago that with these weights we were getting pressures of 50 000 to 60 000 pounds to the square inch, and now that we are imposing weights on locomotive drivers of 16 000 and 18 000 pounds, and on 30-ton freight car wheels of 11 250 pounds, we may be going too far, and placing crushing, or rapidly grinding pressures upon our rails.

It is believed that improvements in terminal facilities have not quite kept pace with other economies in railroad operation and transportation. Switching yards might be better arranged than they are, and cranes might more frequently be used to load and unload goods. Especially is there need for the invention and introduction of some mechanical methods of handling and conveying freight from the receiving doors of the houses to the cars in which they are to be loaded, in order to reduce the large gangs of men now engaged in trucking long distances, at our principal freight stations. As the problem involves both conveying and sorting the freight, it is perhaps insoluble, but it promises sufficient economy and profit to warrant some inventive engineer in considering it carefully.

You may, perhaps, be interested in having your attention called to one or two large foreign railways, and to some novelties in proposed constructions, and first I may say a few words concerning the Pike's Peak Railway, which is just about being opened, and which is the first in this country constructed upon the "Abt" system. This line is 8¾ miles long, and extends from an altitude of 6 600 feet above sea level, at Manitou, Colorado, to one of 14 200 feet at the summit. The system, as most of you know, chiefly consists in applying the power of the locomotive through double cog-wheels, mashing in a rack laid in the center of the

track. This rack is built up of two parallel bars, in which the openings are staggered, so that there are always two teeth of the cog-wheel in full gear, and other teeth are also in contact with the gear, thus greatly adding to the safety and to the ease of motion. The maximum gradient at Pike's Peak is 25 feet per hundred, which cannot be called steep, in view of recent European mountain railways. Thus the "Mount Pilatus" line in Switzerland, built in 1889, on the "Abt" system, and 2.77 miles long, has a maximum gradient of 48 per cent., and the line up Mount San Salvatore, near Lugano (1.02 miles long), which is worked by a wire cable, has a maximum of 60 per cent., or nearly 37 degrees from the horizontal.

These mountain lines seem to have proved very remunerative in Europe, and quite a number of them are in operation or in construction. Even on the Alpine Mountain the "Jungfrau," which until recent years was considered as inaccessible, it is proposed to build a railway with maximum gradients of 98 per cent., or nearly 44½ degrees inclination. This is to be worked as a cable railway, and to be wholly in tunnel, the cars being arranged so as to form a piston, by close fit in the tunnel, to ensure safety in case of the breaking of the cable, by compressing the air, as was formerly done in this country in certain makes of passenger elevators.

A mixed system is intended upon the 65 miles near the summit of the Transandine Railway now approaching completion in South America, between Buenos Ayres and Valparaiso. This mountain section is to be worked partly by adhesion on gradients of 2½ per cent., or 132 feet to the mile, and partly (the locomotives being geared so that they enter upon the track without stopping) by the use of toothed wheels, upon the "Abt" system, over gradients the maximum of which is 8 per cent., or 422.4 feet per mile. The whole line from Buenos Ayres to Valparaiso is 850 miles long, of which 701 miles were completed and opened at the last accounts, and the remaining 149 miles were under construction through the mountain section, involving very heavy work and a large number of tunnels, many of them in the region of perpetual snow, 10 000 feet above the sea. It is being constructed by English engineers and contractors.

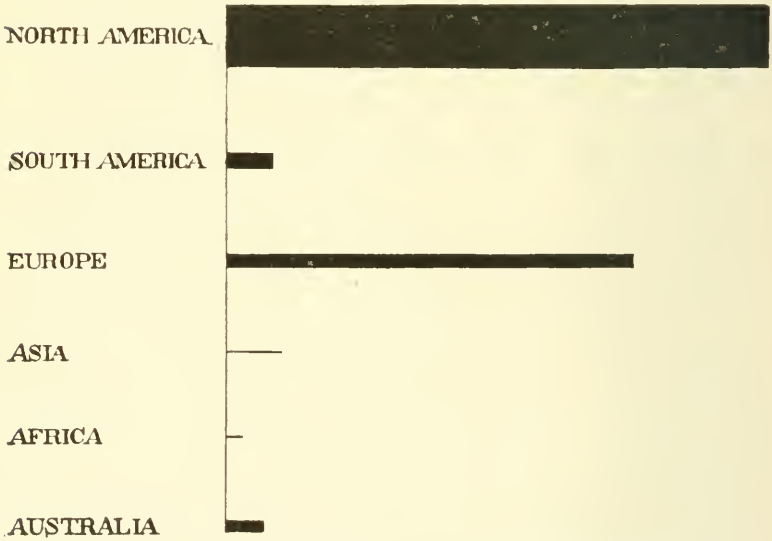
Among railroad novelties may be mentioned the Hydraulic Sliding Railway, a section of which has just been opened near the Crystal Palace in London. This is the same "chemin de fer glissant" which was

exhibited at the Paris Exposition of 1889, and there attracted much attention.

The principal feature of this decidedly novel invention is that it dispenses entirely with wheels, and substitutes therefor a series of iron shoes which carry the railway car, and rest upon a broad flat rail. The shoes are perforated with a very narrow annular orifice, or slit, through which water is forced at high pressure, so as actually to raise the shoes off the rail, and to float the cars upon a very thin water bed between the shoe and rail. This, as may be imagined, reduces the resistance to forward motion to a minimum, experiment having shown that this hydraulic friction on the sliding railway is, on a level, less than one-fifth of the usual rolling friction of the wheels on an ordinary railway. As the whole train is thus afloat on this film of water, it may be asked how impulse is communicated to it from the motive power. This is ingeniously done by a series of water jets issuing from fixed nozzles along the roadway, which are opened and closed automatically by the train itself, and which impinge upon suitable pallets attached under the cars. As may be realized, the consumption of water is great, and other methods of propulsion have been proposed, but thus far without any practical results. This novel system has been mentioned more as a matter of curiosity than as one from which satisfactory results in transportation are to be expected, although the promoters of the scheme claim that speeds of 70 to 125 miles an hour have been obtained, and that no less than 94 per cent. of the fuel required to drive a train can be saved, giving actual experimental figures to prove it. Such data were evidently obtained upon a level line, and we all know that the resistance on a level is but a very small part of that to be encountered upon a railway. The wheel friction, for instance, is 4½ to 5 pounds per ton, while that from gravity on a grade of 52.8 feet per mile is 20 pounds per ton; and there are in addition the resistance from curves and from the atmosphere—the latter, at high velocities sometimes forming an important fraction of the whole. For journal bearings, however, for cranes, and possibly for drawbridges, this idea of supporting a weight upon a thin film of water, issuing at a great pressure, may be worth experimenting with.

One of the great railways of the world, which is eventually to be over 5 000 miles long, is now under construction by the Russian Government across Eastern and Western Siberia. For the present it is to consist of

two isolated sections of railway connecting the navigable waters of rivers in the interior. Beginning at the Pacific end, at Vladivostok on the Japan Sea, the first section is to extend 261 miles to the navigable waters of the Amour; there to connect with 1 590 miles of steamboat navigation. Thence begins another railroad section of 1 895 miles more, which again connects with 1 870 miles of steamboat navigation and thereby with existing railways extending some 1 600 miles further to St. Petersburgh. Altogether there are 2 156 miles of railroad to be built now, at an estimated cost of $103 000 000; and the work is expected to be completed in six years. Russia has now about 20 000 miles of railway for some 92 000 000 of inhabitants. If it is about to enter upon increased activity in railroad construction, there may be an opportunity for the employment of the rapid and cheap American methods and tools, in this, as well as in other portions of the world.



It may be interesting in this connection to inquire as to the relative railroad status of various continents, and having lately had occasion, for another address, to compile and estimate the number of miles of railway in the world on the 1st of January, 1891, the result is herewith graphically exhibited by a diagram. On this diagram the length of the lines represents the aggregate number of miles on each continent, and the thickness represents the ratio of the number of miles of railroad for each 10 000 inhabitants. The actual figures are as follows:

North America is estimated to possess 187 425 miles, or 21.54 miles per 10 000 inhabitants. South America to have 16 000 miles, or 5 miles per 10 000 inhabitants; while Europe has 141 000 miles, being at the rate of 4.06 per 10 000. Asia having 20 000 miles or only a ratio of $\frac{1}{4}$ mile per 10 000. Africa, with 6 000 miles of railroad, averaging $\frac{3}{10}$ of a mile per 10 000 inhabitants, and Australia, ranking nearly with Europe and South America, with 13 000 miles of railroad, and a ratio of 3.42 miles per 10 000 inhabitants. Asia, therefore, and more particularly China, seems to present a field for railroad missionary work, for it cannot fail eventually to ascertain how great a national economy will follow upon the substitution of railroad for other methods of land transportation.

There was occasion, in connection with the schedule of the world's railways already referred to, to estimate this national economy for the United States, and it was found that if we assume that there was a real necessity for the whole volume of the exchange of commodities and movement of passengers (which volume, of course, could not exist at the higher charges) the business done by our railroads in 1889, at the rates of freight and passengers which existed before the railway era, would have cost the nation not less than $12 239 899 980, while the charges actually collected were $992 856 856, thus leaving a difference, or national saving on that basis, of $11 247 043 124, or more than the entire capital invested in our railroads, which, as represented by their stocks and liabilities, amounted to $9 931 453 146.

The average cost of railroads in the United States stands at about $60 000 per mile, while in Europe they are capitalized at about $120 000 per mile, the difference being largely the result of the cheaper methods and designs which original scarcity of capital and labor have led our engineers to develop. The Americans are now the great railroad builders of the world, they execute such undertakings with less expenditures, as measured either in money or in day's work, than other nations, and it seems not impossible that firms of American engineers and contractors shall find it profitable to employ these methods in other countries, let the capital, the labor, or the materials come from whence they may.

Common Roads.

Within the last few years increased attention has been given to the economies to be effected by improving the condition of our highways and ordinary country roads, and several States are now considering as to the

best means of inaugurating the improvement of common roads. Hitherto there was a lesser necessity for such improvement. The great savings were to be effected upon transportation to distant markets, and as capital was scanty in the first settlement of the country, we devoted our first attention to the utilization of the rivers, and next to the building of railroads. In pursuing this course the people have acted wisely, but now the time has come when further savings to the farmers (who have had rather hard competition from foreign sources during the last few years), can be effected by improving the highways over which they haul their produce to the main transportation lines. Various fragmentary estimates have been made of the annual saving to be expected. They have been stated at $15 000 000 for the State of Illinois, and at $6 000 000 for the State of Pennsylvania. These are probably overestimates. For the country at large, if we consider that the railroad moved in 1889—619 530 653 tons of freight, that 27 460 260 tons were moved on the great lakes, and that to this is to be added the goods carried on rivers, and those which go direct by wagon from the producer to the consumer, we see that in the aggregate there must be something like one billion of tons moved annually by wagon. Much of this, of course, goes over city streets, which are already improved, but still if we assume that a saving of ten cents per ton is to be effected in the moving of 250 000 000 tons a year, we see that we can afford to spend four or five hundred millions of dollars in improving our common roads.

An association has recently been formed of Members of this Society to promote the improvement of the highways, and it is hoped that an increasing number of engineers shall give attention to the subject.

Metallurgy.

The year 1890 was notable in metallurgy as being the first in which our production of iron and steel was greater than that of any other nation. No less than 10 307 028 net tons of pig iron were produced; 2 804 829 tons of rolled iron; 2 091 978 tons of Bessemer steel rails, and 1 829 247 tons of rolled steel. Much of the consumption is doubtless owing to the increasing use of iron and steel for structural purposes, and similar engineering works.

Bridges.

One of the important bridges completed during the past year, was the Red Rock cantilever bridge across the Colorado River where it

forms the dividing line between Arizona and California, some 13 miles below the point known as "The Needles," where stood a former bridge on the Atlantic and Pacific Railroad which is replaced by the new structure. The latter is remarkable as being the longest cantilever bridge in the United States, the center opening being 660 feet, while the length over all is 990 feet. Thus each anchor arm is 165 feet, the lever arm being of the same length, and the suspended span is 330 feet long, these proportions, which are not those of maximum economy of superstructure, being dictated by the character of the river bottom. The iron and steel in the structure weigh 1 750 tons, and the erection was done with a traveler of original type which ran on tracks at the same level as the base of the rail, and inside of the trusses; its top extending some 10 feet above the highest point of the truss, and its forward portion projecting about two panel lengths ahead of the front supporting wheels. The erection was begun February 4th, 1890, and completed in eighty working days, and trains were running over the bridge May 10th, of the same year. The structure is proportioned for the heavy live loads as now specified for all important bridges. The chief engineer was Mr. S. M. Rowe, Member of this Society, who intends, I believe, to give us a full descriptive paper upon this bridge; and the superstructure was designed, manufactured and erected by the Phœnix Bridge Company.

The same bridge company also completed during the last year the Terminal Elevated Railway for the St. Louis Merchant's Bridge. This is one of the best examples of modern double-track elevated railway construction at the present time. The structure is for double track, is 1½ miles long, and weighs 5 000 tons. It connects the Merchant's bridge over the Mississippi River with the terminal at the Union Station at St. Louis, and is proportioned for the heaviest live loads now in use.

The same bridge company is now engaged in the building of a bridge across the Ohio River at Louisville. This structure has a total length of about 9 206 feet, consisting of an iron viaduct on the Indiana side, called the Jeffersonville approach, 4 063 feet long; then the following river spans: one span 210 feet; three spans 555 feet center to center of piers; two spans 341 feet, and an approach on the Louisville, Kentucky side, of 2 586 feet. The bridge is for single track, and the weight of the iron and steel is about 12 000 000 pounds. It is expected that the structure will be completed by the end of the present year.

The Wheeling Bridge and Terminal Railway Bridge over the Ohio

River at Wheeling, W. Va., was built in 1890, by the Edge Moore Bridge Works, for the Wheeling Bridge and Terminal Railway, under the supervision of Mr. Job Abbott, Chief Engineer of the Wheeling Bridge and Terminal Railway, and Member of this Society. The total length of the bridge is about 2 100 feet, consisting of one 525 feet span, three 250 feet spans, one 150 feet span, one 108 feet span, all pin-connected, three lattice girder spans of about 100 feet, and 317 feet of viaduct of 33 feet spans generally. The entire structure is for double track railway, and was designed for a load of two 104-ton engines, followed by a train load of 3 000 pounds per foot. The material is mild steel, of which there was 9 000 000 pounds used. The main channel span is 518 feet center to center of end pins, and 80 feet deep center to center of chords. The style of truss used is what is known as the curved chord Pratt. The shoes of this span rest on heavy steel girders, 40 feet long and 5 feet deep, designed to distribute the enormous weight over the tops of the piers. This span weighs 4 000 000 pounds, including the pier girders, which (on the basis of the dead load given on the lithographic stress sheets for the 550 feet span of the Cincinnati bridge), makes this the heaviest truss span yet built in America. The viaduct at the Martin's Ferry end of this bridge was built over a street which necessitated leaving out all transverse sway bracing between the columns. The columns were made stiff enough to transmit the wind and centrifugal forces to the masonry.

The Richmond, Fredericksburg and Potomac Railroad Bridge over the James River, at Richmond, Va., was built in 1890, by the Edge Moor Bridge Works for the Richmond, Fredericksburg and Potomac Railroad, under the personal supervision of Major E. T. D. Myers, General Superintendent, and now President of the road. It is about 2 300 feet long, and consists of eleven pin-connected deck spans of 176 feet each over the river, and 180 feet of viaduct of 30 and 60 feet girder spans at each end. The floor is about 90 feet above the bed of the stream. The river spans rest on iron towers about 46 feet high above the masonry piers. The trusses were designed for a load of two 100-ton engines, followed by 4 000 pounds per foot. The iron floor was calculated for an engine weighing 150 000 pounds, on a wheel base of 18 feet. All the bracing of the towers and the lateral bracing of spans was made of angle iron to resist compression as well as tension, and no adjustable members were allowed in the trusses. All of the riveted members are

of wrought-iron, the eye-bars and pins of low steel. The weight of iron in the whole structure was 3 700 000 pounds.

A notable engineering feat was performed during the past summer in floating into place the main span of the Ohio Connecting Railway Bridge at Brunot's Island, of which Mr. M. J. Becker, Past President of the Society, is the chief engineer. Bridge spans have been floated into place before, notably those for the Conway tubular bridge of 400 feet span, the Britannia tubular bridge of 470 feet span, and more recently for the new Tay bridge with spans of 245 feet, and for the Hawkesbury bridge in Australia, with spans of 416 feet; but the span over the Ohio River is longer than any of those, and is the longest span thus far handled in this way. The span is discontinuous, single track, 523 feet long between centers of end pins, 25 feet wide and 65 feet deep; its top chord is 143 feet above pool water level and the ironwork weighs about 915 tons. It was originally intended to erect it in the ordinary way, upon false works resting on piles and built across the channel. Although this method of erection would comply with the requirements of the law, provided one other span was left open while the main span remained closed, some damage would result to the navigation interests, as the other spans could be used by boats only at uncertain and rare times. The change in the method of erection was dictated by the desire of the Ohio Connecting Railway Company to cause the least possible interference with the navigation of the river. The changed plan, as adopted, involved no change whatever in the iron work of the superstructure.

The span was first erected upon false works very similar to the ordinary kind, but placed in shallow water along shore, and the piles arranged so that coal boats could be inserted at right angles in every other panel but one. The coal boats were of the standard pattern in use on the Ohio River. They were purchased new and sold after the work was concluded at but a small sacrifice. Nine boats were used, each 26 x 130 feet in size. These boats were inserted after they had been partly filled with water, and after insertion, the water was pumped out, and the span, including false works, was thus lifted clear of the supporting piles. The floating structure was then moved out, by means of lines connected to both shores, and towed into position between the piers, when the span was lowered by allowing the water to enter the boats through holes which had been bored in the bottoms for the purpose. The operation, which took place August 19th, 1890, lasted one full day,

but the boats and false works were not removed until the morning of the following day.

The span of 416 feet in the same bridge over the back channel on the other side of the island was erected by using the same false works after shortening them. They were floated around the island into the back channel, and there lowered upon piles which had previously been driven across the channel. Both operations were successfully performed without accident. This method of erection was devised and the work superintended by C. L. Strobel, M. Am. Soc. C. E. It illustrates what can be done in cases where a cantilever is too expensive or is otherwise objectionable; as the method avoids the putting up of stationary false works across the main channel of a stream, and its attendant risks and interference with navigation.

The Newport and Cincinnati Bridge, now in process of construction by the King Iron Bridge and Manufacturing Company, is designed for ordinary highway and street car travel, and has a total length of 2 900 feet. The length of bridge proper, between abutments, is 2 347 feet, made up as follows: one main channel span 520 feet, made up of two 156 feet cantilever arms and a suspended span of 208 feet, two side cantilever spans 252 feet each, two truss spans 254 feet each, one truss span 162 feet, one of 108 feet, and seventeen viaduct spans from 26 to 54 feet each. The bridge has a clear width between trusses of 24 feet and two walks each 7 feet clear, and is provided with a double plank floor supported by iron longitudinal stringers. The stringers, floor beams and connections for the same are designed for a moving load of 100 pounds per square foot of clear roadway and walks, or a 15-ton Aveling & Porter steam road roller. The 108 feet span is proportioned for a moving load of 100 pounds per square foot; the 162-feet span for 85 pounds; the suspended span and cantilever arms for 80 pounds, and the 254 feet spans for a load of 75 pounds per square foot of the clear space of roadway and walks. The trusses of the 162 feet and 254 feet and cantilever spans are made of steel; the shorter spans and the floor system of the entire bridge of iron. The arrangement of spans and the skeleton design of the structure are practically as proposed by Mr. G. Bouscaren, M. Am. Soc. C. E. The calculating, detail designing and shop work has all been done by the King Bridge Company, under the direction of their engineers, Messrs. A. H. Porter and F. C. Osborn, Members of the Society. Messrs. Ferris, Kaufman & Co., of Pittsburgh, Pa., are the engineers for

the company, and the work has been done under their specifications and instructions.

During the past year a single track railroad bridge has been built over the Mississippi River at Winona, Minnesota. - It consists of two fixed spans of 240 feet; one of 360 feet, and of a draw span of 440 feet; the total length, exclusive of trestle approaches being 1 290 feet. The work has been done by the Union Bridge Company, and Mr. G. S. Morison, M. Am. Soc. C. E., is the chief engineer. The same bridge company also built a single track low grade bridge over the Arkansas River at Fort Smith, Arkansas, for the Kansas and Arkansas Railroad Company. It consists of ten spans of 200 feet each, and one draw span of 370 feet, or a total length of 2 370 feet. The piers, instead of being of masonry, are composed of English Portland cement concrete, laid up in mould-boards, and faced with Portland cement mortar after the removal of the mould-boards. They were sunk by the pneumatic process on timber caissons to the rock (which has a maximum depth of 21 feet below low water in the river, and is overlaid with shifting sand) except in the case of two piers where the shallow depth of water precluded the use of the pneumatic method, and where coffer dams were resorted to. The bridge was sufficiently finished on the first of April to allow trains to pass if it had been necessary.

The Tower Bridge across the Thames at London, now approaching completion, was referred to by President Shinn, in his address last year, but the novelty of the design may warrant further description. The intent is to enable foot passengers to cross at all times, and to limit interruptions to wagon traffic to a mininum, the bridge being farther down the river than any of the existing bridges, and a portion of the river traffic requiring more headroom than the 29 feet 6 inches which is afforded by the fixed spans at high water. For this purpose the main floor of the bridge is placed some 40 feet above the water, but the central span has also a second girder and floor giving 140 feet clear headroom at high water. The total length, including approaches, is 2 640 feet, of which 880 feet is across the river proper. This is divided into three spans, the two side spans being of the braced suspension type, 270 feet clear, and the central span being 200 feet clear. The latter is composed of two leaves, weighing nearly 1 000 tons each, which fold up vertically on their hinges, and thus leave a passage for masted vessels 140 feet in the clear. The width of roadway is 60 feet on the side spans,

and 50 feet on the central span. When the folding leaves of the lower floor are thus raised, all vehicular traffic must be suspended, but foot-passengers are then to be hoisted to the upper floor on passenger elevators, and let down similarly on the side.

There was opened last October in the southern part of Chili, a viaduct for the Chilian State Railway, which is, perhaps, the highest in the world. It is 333 feet above the level of the Mallen River, from which it takes its name, and is 1 419 feet long, divided into five spans each 232 feet in length, and some approach spans. The total weight is 1 550 tons, and the designs were prepared by Mr. V. Amelio Lastaná, a Chilian engineer. Among high bridges, mention may also be made of the St. Giustena highway bridge in the Tyrol, which consists of an iron arch of a clear span of only 197 feet, at a clear height of 453 feet above the bottom of the ravine which it crosses. Naturally no false works were used, but it was built out from the two abutments simultaneously by traveling cranes, a cable, carrying a cage, being stretched across the ravine, and aiding materially in the work, which was completed in 1888.

The remark is sometimes heard that engineering works, and particularly bridges and viaducts, are great eyesores to the artistic public, and that engineers are rectangular utilitarians who pay no attention to looks. Indeed, it is said that part of the opposition to the extension of elevated railroads in some of our cities, is because they (the elevated railways) are very ugly. How far an engineer will be justified in spending other people's money in ornament will depend upon the circumstances of the case, but as wealth and taste have increased, there seems to be a disposition on the part of capital to take a more liberal view of this matter than heretofore. Engineers, therefore, in designing new structures may profitably inquire how they will look from an æsthetic point of view, and in many cases artistic effect will follow, simply by arranging the outlines in accordance with the lines of maximum strains. Among recent works this may be illustrated by reference to the Merchants' bridge at St. Louis, the Thames River draw, and the Eiffel Tower, in all of which cases the lines of the structures were designed by following closely the lines of the greatest strains. European engineers have always given greater thought than we to the finished appearance of their works, particularly in cities, and this is well illustrated in the new Highway bridge at Hamburg, Germany, built by Mr. C. O. Gleim, our

corresponding member, which is entered through one of the most beautiful portals thus far built.*

Buildings.

It may be interesting to engineers to note a new departure in buildings. The use of passenger elevators having rendered the upper stories of houses as accessible and pleasant as those lower down, and the profitable results of investments in high buildings having brought in a greater rental from real estate than was hitherto believed possible, an evolution is now in progress in buildings in this country, somewhat similar to that which has taken place in American bridges, and to a certain extent the same engineers are being called upon to design the ironwork and framing. Being best acquainted with what has recently been done in this direction in Chicago, I may be permitted to draw my illustrations from that city. It now possesses some eight or ten office buildings from ten to fourteen stories high, and some six or eight more are now well under way. One of these, the "Women's Temperance Union Temple," is to be thirteen stories high, and another, the "Masonic Temple," is to be twenty stories high, being 113 x 170 feet on the ground and 274 feet high above the sidewalk.

The salient feature in the mode of construction which has rendered these high buildings possible, is that the principal portion of the weight, that of the floors and the roofs, instead of being carried upon the outer walls, is now supported by an internal skeleton of steel columns, placed tier upon tier in the building, and rigidly connected with the girders and floor beams which carry the cellular arch bricks which span and form the floors. The outer walls become a mere skin to keep out the weather, and in the more recent instances even this outer shell rests upon the girders which span the space between the columns; each story is thus practically independent of the others, save through connections at the posts. In the case of the Masonic Temple the outer piers are introduced simply for architectural effect, and inside of them are steel columns which carry all floor and spandrel loads. This building has two lines of vertical bracing, running from top to bottom through the narrow way of the structure.

This skeleton system of construction, in which the outer walls need be

* The various bridges and structures above mentioned were illustrated by stereopticon views.

no more than 8 inches thick, not only allows of high buildings, but it economizes space and land, generally expensive, and it admits of leaving the front almost all windows, thus giving to the apartments of the building a luxury of light hitherto quite unknown. The construction must, of course, be entirely fireproof, and this, it is now believed, has been secured by improved methods. This method of steel construction has naturally led to the application of the modern erecting methods, which have proved so rapid, effective and economical in the putting up of bridges, and it thus substitutes steam-power for the armies of men formerly employed about the construction of the walls. Thus, in the erection of the new hotel, the "Chicago," 100 feet by 165 feet on the ground, fourteen stories high and 170 feet above the sidewalk, all the steel columns, girders and floor beams were hoisted and put in place by a self-propelling rotary crane, which also hoisted itself from story to story. It ran over a movable track so as to reach every portion of the structure, and was worked by one man, who performed all the manipulations and did the firing. As soon as one story is erected an inclined track is laid, and the crane hauls itself up to the next story. When the top is reached the machine is taken to pieces and lowered down, after having handled, in this particular case, 1 700 tons of steel with a crew of 20 men, at the maximum rate of two stories per week, including the columns and beams complete. At one time the frame-work was carried up six stories above all other construction. The building has vertical bracing from top to bottom, forming a tower about 60 x 80 feet in the center of the long side of an inner court. The steel work was furnished and erected by the Keystone Bridge Company.

It may be interesting in this connection to give an account of the way in which the foundations under these great buildings are prepared. The subsoil of Chicago consists of blue and gray clay, which grows softer at some distance below the surface. It yields to concentrated weight, and it is not safe to load it with more than 1½ to 2 tons to the square foot.

Formerly heavy buildings were founded upon wooden piles, but moisture being excluded by the clay, the piles rotted and allowed the buildings to settle. The present practice is to use large footing stones for moderate structures, but for great concentrated weights a bed is formed, of rails enclosed in concrete, under the piers which carry the iron or steel columns, so as to float the weight over the clay with a press-

ure of 1½ tons to the square foot, increased on rare occasions to 2 tons; and on top of this foundation a course of iron or steel I-beams is placed to carry the masonry of the pier on which the steel columns are to rest.

Electrical Engineering.

The most rapid and remarkable engineering advance during the past year has been in various applications of electricity. It has been set to performing all sorts of duties, in addition to its former uses in the telegraph, the telephone, and the electric light. Now it is not only supplying motive power about our cities to run sewing machines, printing presses, ventilating fans, various grinding mills, elevators and church organs, and turning draw-bridges, but it is also being applied in machine shops to run cranes, hoists, shafting and machinery; also in mines to undercut and haul out coal, and to pump water. Also to propel launches and to handle guns and ammunition; and it has recently been applied to heating, cooking, soldering and welding, so that it seems difficult to foresee the future limits to its various applications.

The largest growth of this development, however, has been in street car propulsion. Ten years ago there were in the United States 3 500 miles of street railways, all operated by horses and mules; now the street car mileage of the country is as follows:

5 713	miles	of track,	operated	by	animal power.
527	"	"	"	"	cables.
554	"	"	"	"	steam motors.
2 931	"	"	"	"	electric motors.
9 725					

As the first commercially successful electric street railways date back only to the beginning of 1888, the 2 931 miles now operated have practically been built or equipped in three years, and the aggregate is still growing very fast; no less than 781 miles having been opened during the four months preceding the 1st of February of this year, to which date the above figures were made up. This 2 931 miles of electric railroad is operated by 4 407 motive cars, drawing some 6 000 trailers. Almost the whole of it is equipped upon the overhead trolley system, and not only are grades of 10 to 14 per cent. surmounted, but the roads are operated at speeds of 7 to 10 miles per hour, at a cost materially less than that of animal power. The maximum speed may be stated at

20 miles per hour, and the maximum of a single electric car motor at 75 horse-power, so that for speed, for power to ascend steep grades and for economy of operation the electric railroad is far superior to that operated by animals.

It has been suggested that these great strides of electricity as a motive power point to an eventual superseding of the locomotive in the operation of the ordinary railroads of the country, and that the economy resulting from the generation of the power with stationary engines, together with the saving of dead weight effected by substituting electric motors for steam locomotives, will more than warrant the expense of changing the present installations.

I doubt whether this is likely to be the result so long as the electric power is obtained from a wire overhead, chiefly because this method involves the abandonment of having each locomotive an independent, self contained motor, which can be tossed aside in case of accident in the generation of power, without stopping the operation of the whole road, as would be the case were either the stationary engine, producing power, or the distributing wire to give out in an electric system; these parts of the plant being easy to watch and to repair in and about a city, but difficult to care for in the open country.

The advantages of having self-contained electrical motors may, perhaps, be secured by improvements in storage batteries, and experiments are therefore eagerly being made by many inventors to reduce their present prohibitory weight. The most successful seems to be that of the Waddell-Entz storage battery car, which was tested on the 4th of May in Philadelphia, and which is reported to have worked quite satisfactorily. By using copper and iron plates instead of lead, and an alkaline instead of an acid solution, the weight is said to have been reduced to about one-half that of former storage batteries. Be this as it may, it seems now not unlikely that very much greater speed will be attained with electric motors than any which have yet been practically secured. There are many proposals for this purpose, and it is understood that an experimental line on the "Weenes Electric System" has already attained a speed of 115 miles per hour, at which speed the trains generally left the very imperfect track experimented upon, and that with a better plant it is confidently expected that this, as well as some other electric systems, will be able to operate at speeds of 150 miles per hour. At this great velocity the atmospheric resistance becomes a very impor-

tant element, and experiments will become necessary to ascertain the best form to be given to the trains. I may say in this connection that I made some investigations on this subject some years ago, and became satisfied that even with our present trains a considerable portion of the resistance from air, and of the consumption of fuel, might be saved upon our fast trains, by a few modifications of our present railroad rolling stock.

Some additional statistics may assist in giving an impression of the growth of electrical engineering. The total number of incandescent lights in the United States operated from central station plants is stated at 1 740 000, and the total arc lights at 154 000. The horse-power of engines employed in this connection is 400 000, in 1 379 plants, and the capital invested is $126 758 500. In addition to the above, there are said to be 900 000 incandescent lamps and 25 492 arc lamps operated from isolated plants. The whole number of telephone companies' licensees of the American Bell Telephone Company is 51, and the number of special licenses is 9. The combined capital is stated to be $85 000 000. The telephones in the hands of licensees and under rental, number 411 511, and the number of subscribers is stated at 171 454. This includes both the American Bell Telephone Company and the American Telephone and Telegraph (long distance) Company; the longest distance over which conversation by telephone is now daily maintained being 750 miles—from Portland, Me., to Buffalo, N. Y.

The Society's Affairs.

You will be pleased to know that there is sustained interest in the Society, as evidenced both by new applications for membership, and by attendance at the meetings. I may say, however, that the supply of papers for the *Transactions* has not been as liberal during the past year as would have been desirable, and that too many of them are postponed until the last moment, at Convention time. As the *Transactions* constitute for many members the only intercourse which they have with the Society, it is desirable that material, in the way of engineering papers, shall be both abundant and regular.

Recent growth and improvements in the technical press, in which a number of able editors have been giving accounts of engineering works as fast as they have been executed, has probably interfered with the preparation of papers. Engineers have found it easier to furnish notes to those editors than to prepare a complete paper for the Society.

The search made for information, however, through the technical press in the preparation of this address, has shown how imperfect and scanty such hurried accounts of current works must necessarily be; how much more valuable to the engineering student is a paper carefully prepared for our *Transactions*, and how much more the latter are likely to add to the reputation of an engineer. It is therefore hoped that the engineers who are carrying on important works and experiments shall prepare detailed papers for the Society. The current accounts which appear in the technical press will merely whet the appetite for a full and accurate statement of the difficulties encountered, the means taken to overcome them, and the results finally achieved.

Especially is it desirable that such papers shall be discussed fully by the members, such discussions being not infrequently even more valuable than the papers themselves, by bringing out statements of the best engineering practice upon a particular subject. In order to promote this, the Secretary will send out advance copies of papers which are to be discussed to members who are likely to have something to say about them, either verbally or in writing, and each member is requested to advise the Secretary of the class of subjects in which he is most interested.

It is expected that the Columbian Exposition of 1893 shall afford to American engineers an opportunity to repay in part the heavy obligations contracted to foreign engineers in 1889. The members of this Society who, with members of the Mining and Mechanical Engineers' Societies, visited Europe in that year, were received with unexpected magnificence. They were treated not as cousins but as brothers, and their visit was one long series of delicate attentions and entertainments, not only from engineers, but from all classes of the community.

This began with the very landing in England, where the Americans were everywhere received and entertained by the engineers and the municipal authorities, and showered with private invitations and receptions. Not only did a large number of the prominent members of the British Institution of Civil Engineers gave up their business and time to the showing to their visitors the principal engineering works, either completed or in progress, but on that occasion the important engineering and manufacturing establishments usually hermetically closed to visitors, were thrown wide open to the Americans, the managers attending upon them to afford every desired information.

In London, by the express sanction of the Lord Mayor, Aldermen and Court of Common Council, we were given a dinner in Guildhall; the second time, it is said, in more than one hundred years that this noble hall has been used for any entertainment not given by the Guilds themselves; and in addition to the examination of some twenty-nine engineering works and establishments, the programme included invitations to visit some seventeen objects of interest, as tourists rather than as engineers. These visits were paid, not in the usual way with ordinary sight-seers, but under the happiest auspices. Thus Westminster Abbey was seen under the favor of the Dean, who gave us an address in King Henry VIIIth's Chapel, upon the historical associations of the Abbey. We were, when visiting the Lambeth Episcopal Palace, there received by the Archbishop of Canterbury, who gave us a most interesting talk upon the events which had occurred therein. In visiting the Palaces of the Crown, the American engineers, instead of being limited to those portions usually opened to the public, were by special permission of the Queen, shown the private apartments; and I happen to know, that upon the visit to Windsor Castle, the Queen had changed her own plans in order that the engineers might be admitted upon the day most convenient to them.

These attentions, together with a large number of private invitations and meetings with distinguished persons, impressed us greatly as to how good a thing it is, in Europe, at least, to be an engineer.

In France, the same kind of attention and cordiality was shown to the American engineers, who were received upon landing by a delegation of the leading French engineers, taken to Paris on a special train, and that very night invited to an open air fête and illumination given in one of the parks by the municipality. Later on, during a series of some thirty-five visits to engineering works and points of interest, we were received and entertained by a delegation of the municipal council, and also by the President of the Republic, who, being himself an engineer, told us that he received us as comrades, rather than as visitors, gave our officers the loan of his box at the opera, and invited them to a garden party at his palace. Indeed, the entertainments and invitations to the engineers, while in Paris, were so numerous that but a portion of them could be accepted, and we were at times heartily ashamed of the small numbers who were able to attend on most interesting occasions.

In Germany again, the small number of the party who were able to

spare the time to accept the invitation of the German engineers to visit them were most magnificently received, and were there again made aware how high our profession stands in Europe in the ranks of the general community. We hope, however, to reciprocate in part. An organization was formed last week in Chicago, particulars of which will be laid before you, to provide headquarters for the engineers who may visit the Columbian Exposition of 1893, and to invite them to an engineering congress. This will need to be supplemented by us, with some invitations to foreign engineers to visit this country on that occasion, and with arrangements to entertain them in various cities. It is hoped that provision will be made to enable them to see our engineering works to the best advantage, and to meet the leading men who will best represent the growing importance and consideration accorded to our profession.

For we may as well acknowledge the fact, that engineers in Europe hold a higher status among professional men than they do in this country. They are there looked upon as the leaders of the material development of the present age, and stand fully as high as men of any other profession. They are in chief charge of many industrial operations which are in this country managed by so-called practical men, and are consulted and employed before capital engages in any novel or important manufacturing enterprise.

It has not been always so. A century or so ago the English engineers seem to have occupied a far less desirable position than they do to-day. This is best illustrated by the compensation they then received. Thus the biographer of Telford, says that his average income did not amount to more than is paid to the resident engineer of any modern railway, and that during the twenty-one years that he acted as principal engineer of the Caledonian Canal the amount paid to him was exactly $1 185 a year. Brindley is stated by the same authority to have been paid at the rate of 87 cents a day, while in chief charge of the surveys for the canal between Manchester and the Mersey, while now many English engineers are in the receipt of incomes fully as large as those of our railroad presidents.

This has been the result of the higher standards of acquirements and business qualifications which have obtained in the profession, and of the increase in accumulated capital. As more important enterprises were undertaken, the disastrous results of entrusting them to half-trained men became more apparent, and the Jack-at-all-trades was replaced by the engineer.

A like evolution appears to be taking place in this country, not only through the more complete education and training which are being given in the technical colleges, and through the educational influence of societies of engineers like ours, but also through the great change in methods, which, during the past ten years, have led so many of our members to open offices for themselves either as civil engineers to design and carry out works, or as consulting engineers to place their experience and knowledge at the disposal of the public.

If, together with this better equipment for the pursuit of our chosen profession, the present high standard of professional honor and integrity be maintained, there are good grounds for believing there will result within the next few years a marked improvement in the independence, in the standing, and in the emoluments of the civil engineer.

ERRATA.

Volume XXIV, No. 5, May, 1891, page 333, twenty-sixth line from the top, "Lieutenant-Governor Colder" should read "Lieutenant-Governor Colden."

Volume XXIV, No. 5, May, 1891, page 355, first line of foot note, "Mayor H. W. Clark" should read "Major H. W. Clarke."

CORRECTION.

Mr. J. M. Wilson, M. Am. Soc. C. E., calls attention to an error on page 339 in the paper on "Beginnings of Engineering."

Major John Wilson (his grandfather) was not a graduate of West Point as stated. Major Wilson was born near Stirling, in Scotland, and was educated there and at Edinburgh University. His father was an officer in the British army during the Revolutionary war, and his mother was a native of South Carolina. He was naturalized in South Carolina and served at Charleston in the war of 1812–15 in the construction of military works; and at its close was commissioned as Major in the Corps of Topographical Engineers, U. S. A. Afterward he was appointed Chief Civil and Military Engineer of South Carolina, and later still served the State of Pennsylvania in the location and construction of the Columbia Railroad, and on other surveys. (For further details, see page 46, Vol. 2 of "Contemporary Biography of Pennsylvania.")

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

477.

(Vol. XXIV.—June, 1891.)

REPORT OF THE COMMITTEE ON THE CAUSE OF THE FAILURE OF THE SOUTH FORK DAM.

WITH DISCUSSION.

To the American Society of Civil Engineers:

The Committee appointed June 5th, 1889, to visit the dam of the South Fork or Western Reservoir, in Croyle Township, Cambria County, and investigate the cause of its failure, following the great rain of May 30th and 31st, 1889, visited the dam as soon as practicable after the re-establishment of railway communication with the locality.

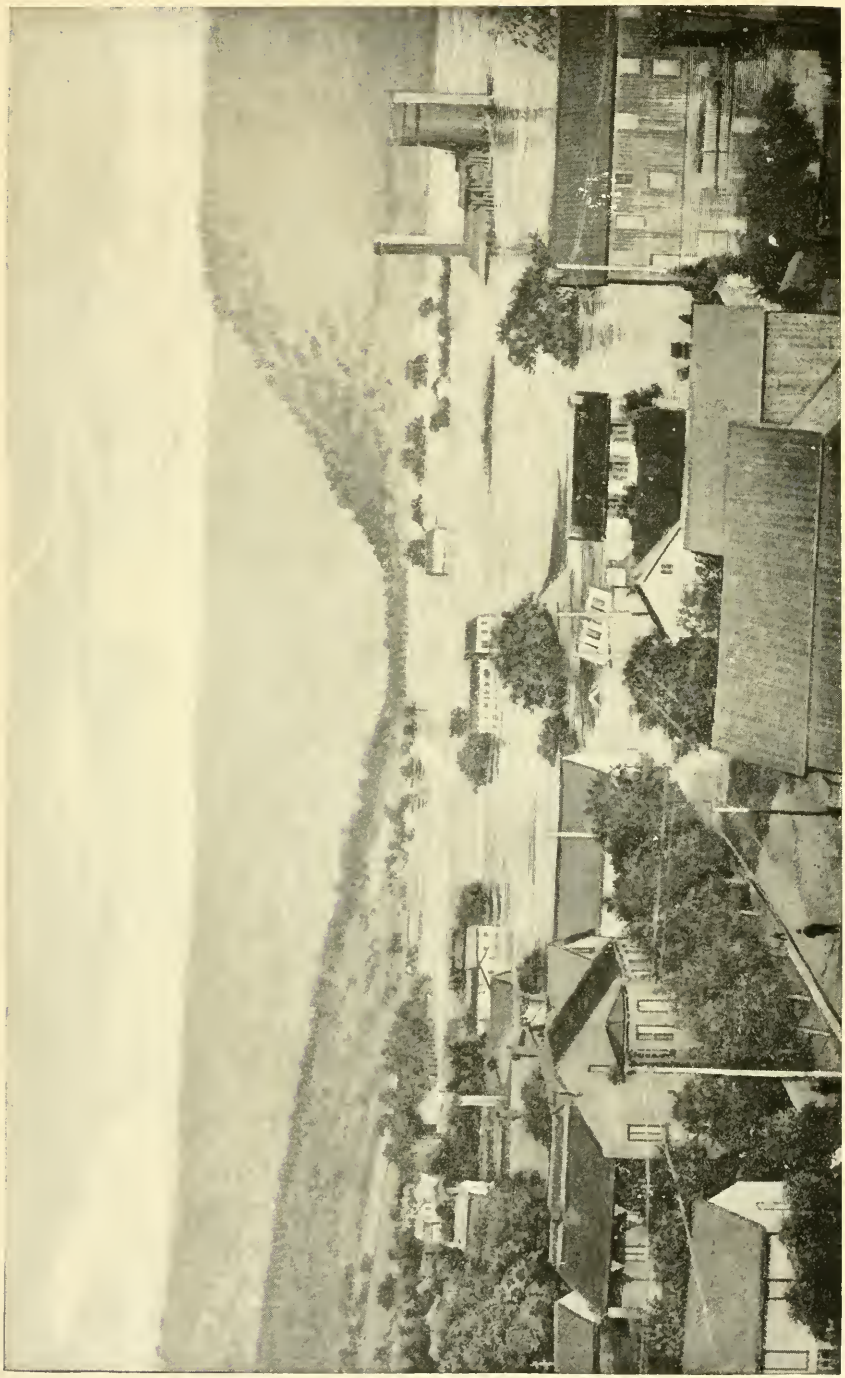
On their passage up the eastern slope of the Alleghany Mountains they observed many evidences of the magnitude of the flood, particularly in the destruction of bridges. Among these were three large bridges over the Juniata River, on the main line of the Pennsylvania Railroad, between Tyrone and Lewistown, besides a great many highway bridges. Four large railroad bridges over the west branch of the Susquehanna River were carried away between Lockhaven and Sunbury on the line of the Philadelphia and Erie Railroad, and many smaller structures were destroyed or injured by the flood. These were undoubtedly expected to provide safely for the passage of the greatest volumes of water of which there

was any experience, and the destruction of so many of them is evidence of the extraordinary character of the flood. The destruction of one of the bridges on the Juniata seemed due to an accumulation of [illegible] trees, stumps and brush above it, closing the waterways and damming up the flood.

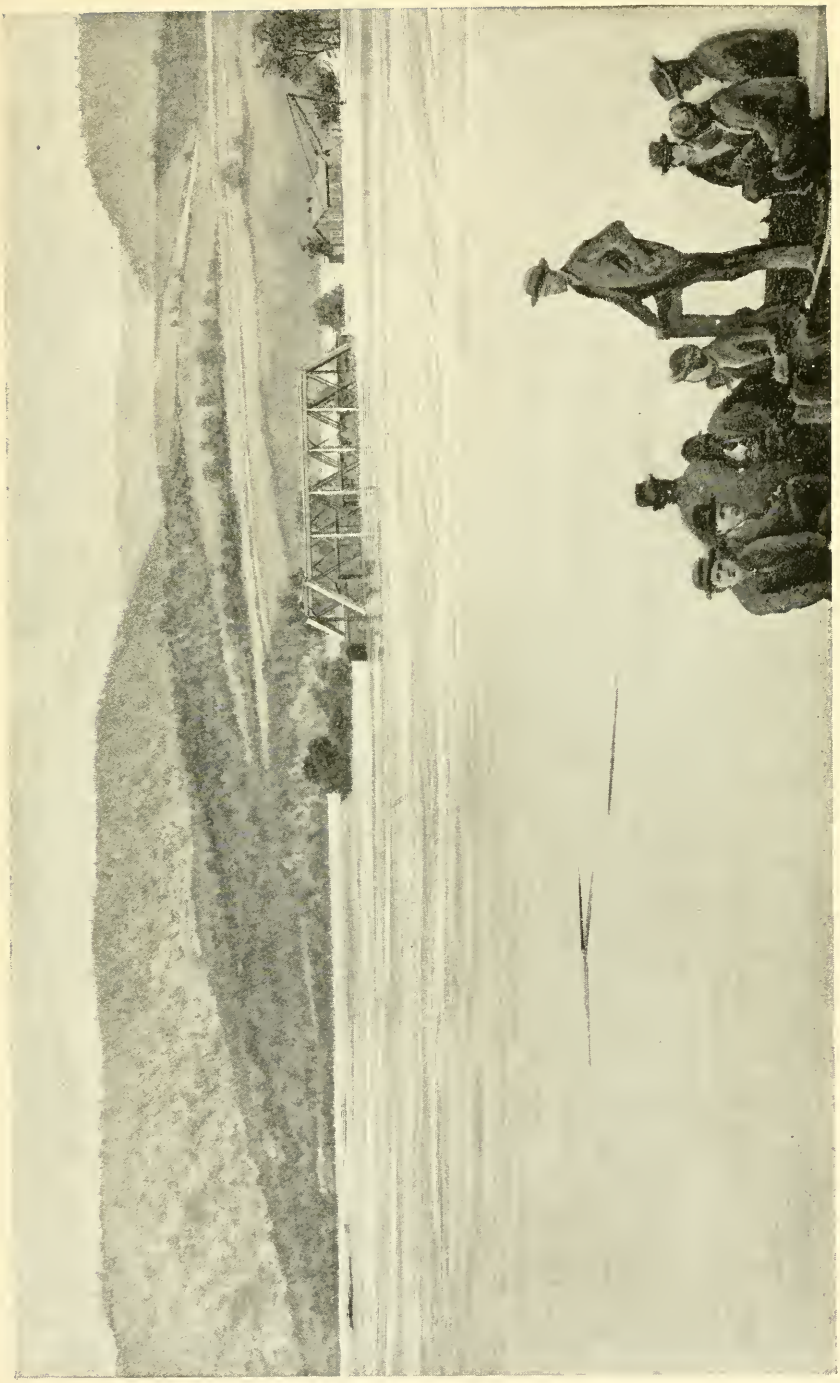
Plates XXXVI, XXXVII and XXXVIII are from photographs of the wreck of the bridge of the Pennsylvania Railroad over the Juniata River, at Lewistown, which is about 45 miles from the nearest part of the summit.

The easterly boundary of the 48.6 square miles of water-shed supplying the South Fork Reservoir is the summit of the Alleghany Mountains. The rain-fall was much greater on the easterly than on the westerly slope. By Plate XLIX and Table No. 1, it appears that on the easterly half of the circle of 100 miles in diameter, of which the middle of this water-shed is the center, the observations indicate an average rain-fall of 6.64 inches, and on the westerly half 2.76 inches, and it is obvious, that except for the failure of the South Fork Reservoir Dam, the damage caused by the flood would have been less on the western than on the eastern slope.

Subsequently to their visit to the dam, the Committee viewed the line of the Pennsylvania Railroad from South Fork Station to Johnstown, a distance of about 9 miles. It follows the Conemaugh River, which flows in a deep valley, the average descent is about 33 feet per mile, the maximum grade being 52.8 feet per mile; but the river, being more circuitous, is about 3 miles longer, its descent between the same points being substantially the same, or about 300 feet. The rise of the water during the flood was generally about 30 feet; at some points, however, it was considerably more. The flood washed away all the bridges between South Fork Station and Johnstown, except the stone bridge near the Cambria Iron Works, and nearly all the embankments and a great part of the tracks. The greatest destruction was within about 5 miles of Johnstown. The streams on both sides of the mountain range had risen very rapidly during the night between Thursday and Friday, but the waters on the eastern slope had reached their flood height earlier on Friday morning than those on the western slope. Nearly the entire working force of the Western Division of the Pennsylvania Railroad had therefore been sent to the Middle Division, and were scattered along the Juniata and Susquehanna Rivers, when the breaking of the South Fork

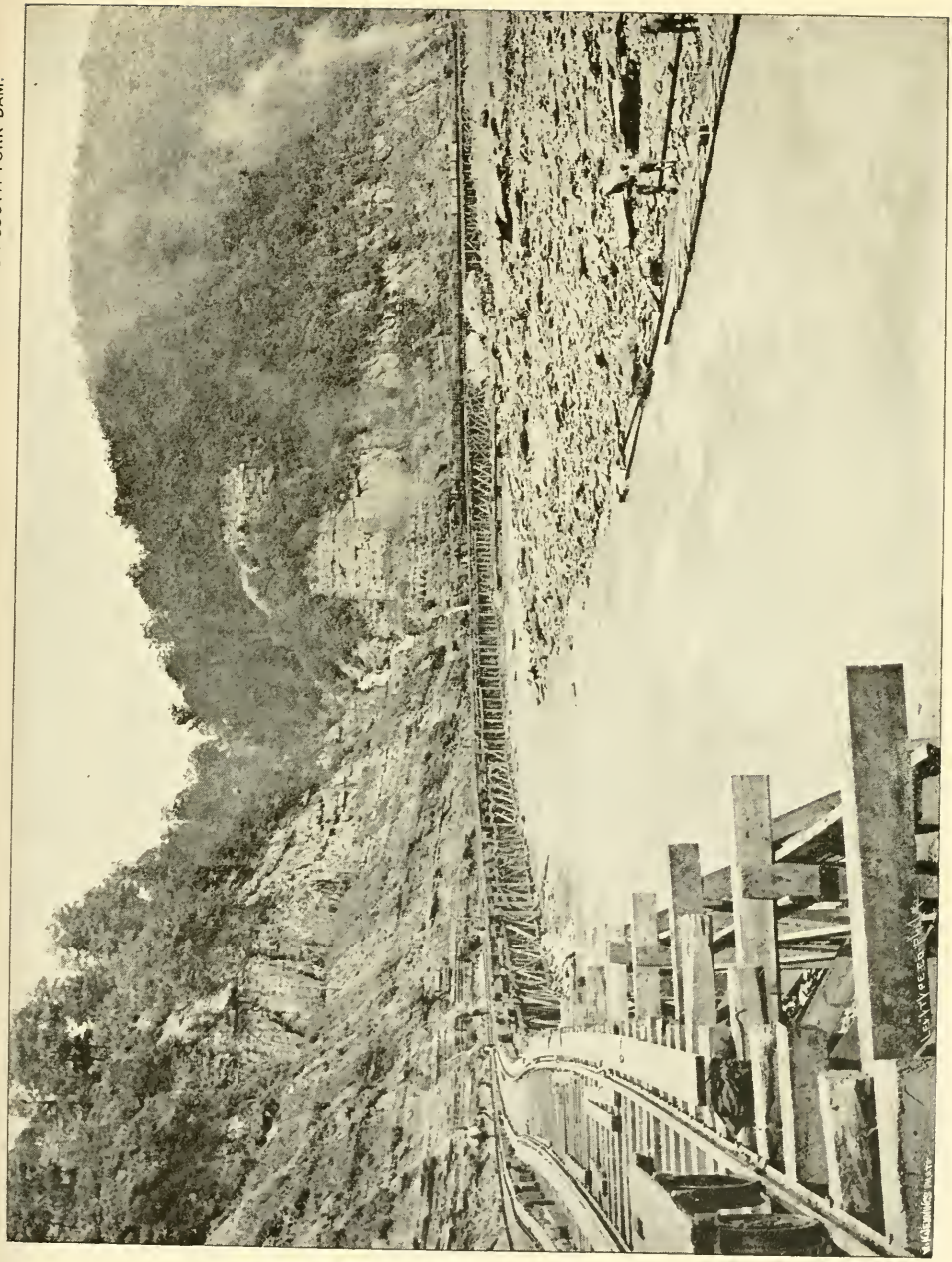


HIGHEST WATER IN LEWISTOWN. RIVER TO EXTREME RIGHT.



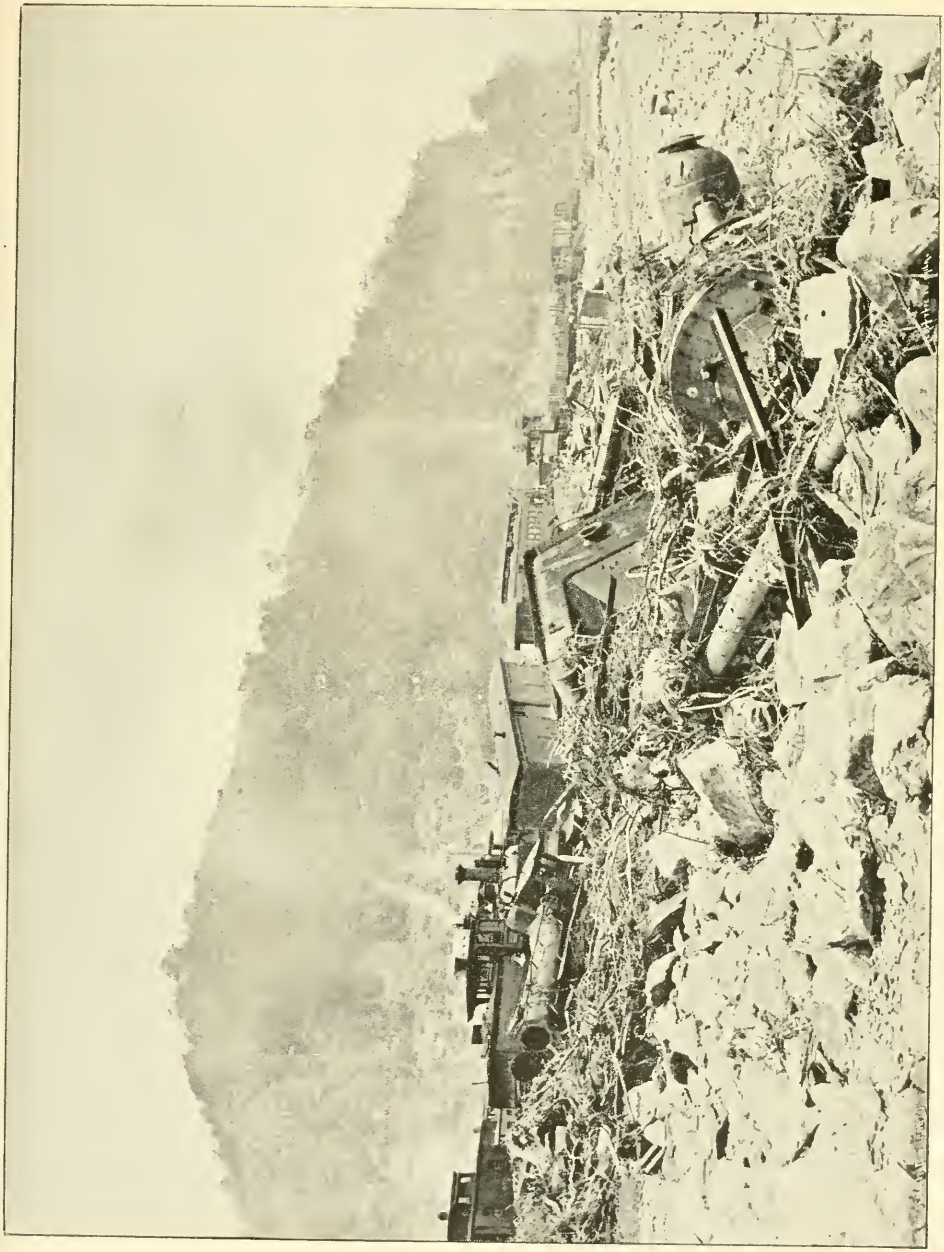
BRIDGE AT LEWISTOWN, (LEWISTOWN DIVISION, PA. R. R.), TAKEN AT HIGH WATER AFTER THREE SPANS HAD FALLEN.

BRIDGE AT LEWISTOWN (LEWISTOWN DIVISION, PA. R. R.), SHOWING WRECK AFTER THE SUBSIDENCE OF THE WATER.



REPORT ON SOUTH FORK DAM.

VOL. XXIV, NO. 477.
REPORT ON SOUTH FORK DAM.



Reservoir Dam on Friday afternoon suddenly caused the destruction of the railroad in the Conemaugh Valley, with a fearful loss of human life and the annihilation of private property amounting in value to millions of dollars. All means of communication between the inundated sections of the country had been destroyed, and the only reliable line of access for immediate relief to the flooded districts in the vicinity of Johnstown was from the west. When on Saturday morning the full extent of the disaster became known, prompt measures were at once adopted by the public authorities and voluntary organizations for the relief of the sufferers and for substantial assistance to the distressed.

The early restoration of the railroad and the re-establishment of communication were among the necessities most urgently felt. The officers of the Pennsylvania lines west of Pittsburgh were called upon during Saturday for men and materials, and on Sunday night they reported at Johnstown for duty with 1 250 men, fully equipped with tools, provisions, materials and supplies; and from Monday morning, June 3d, these men worked day and night, through rain and flood, until Friday, June 14th, when they met, at Bridge No. 6, $4\frac{7}{10}$ miles above the starting point at the Stone Bridge, in Johnstown, the regular forces of the Pennsylvania Railroad working from the east westwardly. During these eleven days the western forces had built 3 200 lineal feet of trestle work, from 15 to 50 feet in height, laid 29 000 lineal feet of main track, and 9 000 lineal feet of siding and yard tracks, with numerous switches and connections, requiring heavy grading in many places. Plate XXXIX is from a photograph of the Buttermilk Falls trestle, ½ mile east of Conemaugh Station, 2 200 feet in length, double track, which was completed in forty-eight hours.

The New York and Chicago Limited Express, which left Pittsburgh on the day of the flood at 7.15 A.M., had reached South Fork Station, when it received orders at the telegraph tower, just west of the mouth of South Fork Creek, to stop on account of some damage done to the tracks east of South Fork, in the vicinity of Lilly, on the western slope of the Alleghany Mountains. At the same time the Day Express, which left Pittsburgh on the same day at 8.10 A.M., had proceeded to the station at Conemaugh, when it received orders to wait for the reasons given above. The Limited Express was standing at the telegraph tower at South Fork when the dam broke, and the conductor and engineer of the train seeing the volume of water pouring down upon them from South

Fork Creek, disobeyed orders and proceeded with their train, as fast as they could, across the bridge and on eastwardly to high ground. By doing so, they saved themselves from certain destruction, which would have followed had they remained at their posts, as the bridge was bodily swept away and the whole force of the flood rushed against the embankment of the railroad, tearing away the telegraph tower, and carrying the plate-girders composing the bridge over the main Conemaugh River some 300 or 400 feet up stream. The Day Express stood in two sections on the tracks at Conemaugh Station, opposite the round-house, when the flood came upon them. Some of the passengers had left the train before and had gone into the town; but a number were in the train during the flood, which rose to the height of the windows in the cars and the boilers of the engines, burying them with driftwood and debris. The passengers that were lost from the Day Express, which were twenty-eight in number, were drowned in the attempt to save themselves by running from the train to the higher ground on the north side of the tracks. Plate XL is from a photograph of the wrecked train.

We are informed by the Secretary of the Flood Relief Commission that their "records to January 11th, 1890, show that there are known to be lost in the Conemaugh Valley by the flood of May 31st last, 2 280 persons." Of these, 1 675 bodies have been recovered, 1 021 of which have been identified. Bodies are recovered, from time to time, as excavations are made in the debris, and it is possible that a number of persons may have been drowned of whom there is no trace, as there was a considerable floating population in the valley, but from the best information we can obtain we think the total loss of life by the flood did not exceed 2 500.* We have found it impracticable to obtain definite information of the loss of property caused by the flood, but as the result of

* Since the above was written the report of the Secretary of the Flood Relief Commission dated June 30th, 1890, has been received, from which the following is an extract:

"The location being unfavorable for easy escape from the waters let loose from the dam above, the difficulty was greatly increased by reason of a general inundation which existed prior to the breaking of the dam. Nearly the whole city was already submerged to a depth of from 7 to 10 feet, and even had timely warning been given of the impending danger, the result would have been but little changed, as escape through the streets was practically, by reason of the high water, cut off. The most careful investigation, continued to the present time, shows the number to have been 2 142. That is, it is known that persons to this number were in Johnstown at the time of the flood who have not been heard of since as being alive. Some of these may be living and may yet be discovered, but the number given above is not likely to be much reduced. It is probable, too, that the number lost is slightly more than this, but as the additional number could only be composed of persons temporarily in the city, and who had not formed acquaintances or become so identified with a neighborhood as to be missed, it necessarily cannot be large."

recent inquiries of persons in official positions and having the best opportunities of knowing, we estimate the loss by individuals and corporations as between three and four millions of dollars.

At the South Fork Reservoir we examined the remains of the dam, made a survey of the same and its surroundings, obtained photographs of it and of the upper part of the wasteway, copies of which are given in Plates XLI to XLVI. We also made inquiries of persons living in the vicinity and others acquainted with the dam, some of whom witnessed the disaster. Subsequently we have gathered from others, by personal inquiry and correspondence, information as to the rain-fall during the storm which led to the disaster, and as to the construction of the dam and its history. We are under great obligations to Messrs. T. T. Wierman and Antes Snyder for researches in the State records and published documents which have furnished the material for the historical part of this report.

We would call attention to the earth layers of which the dam was composed, which are shown so plainly in Plates XLII and XLIII on each side of the break, also to the abruptness of the banks over which the water fell after the rock backing had washed out, as evidences of the solidity of the earth-work, and that the failure was not due to any leak through this part, but that it was from the overflow of the crest, as testified to by observers.

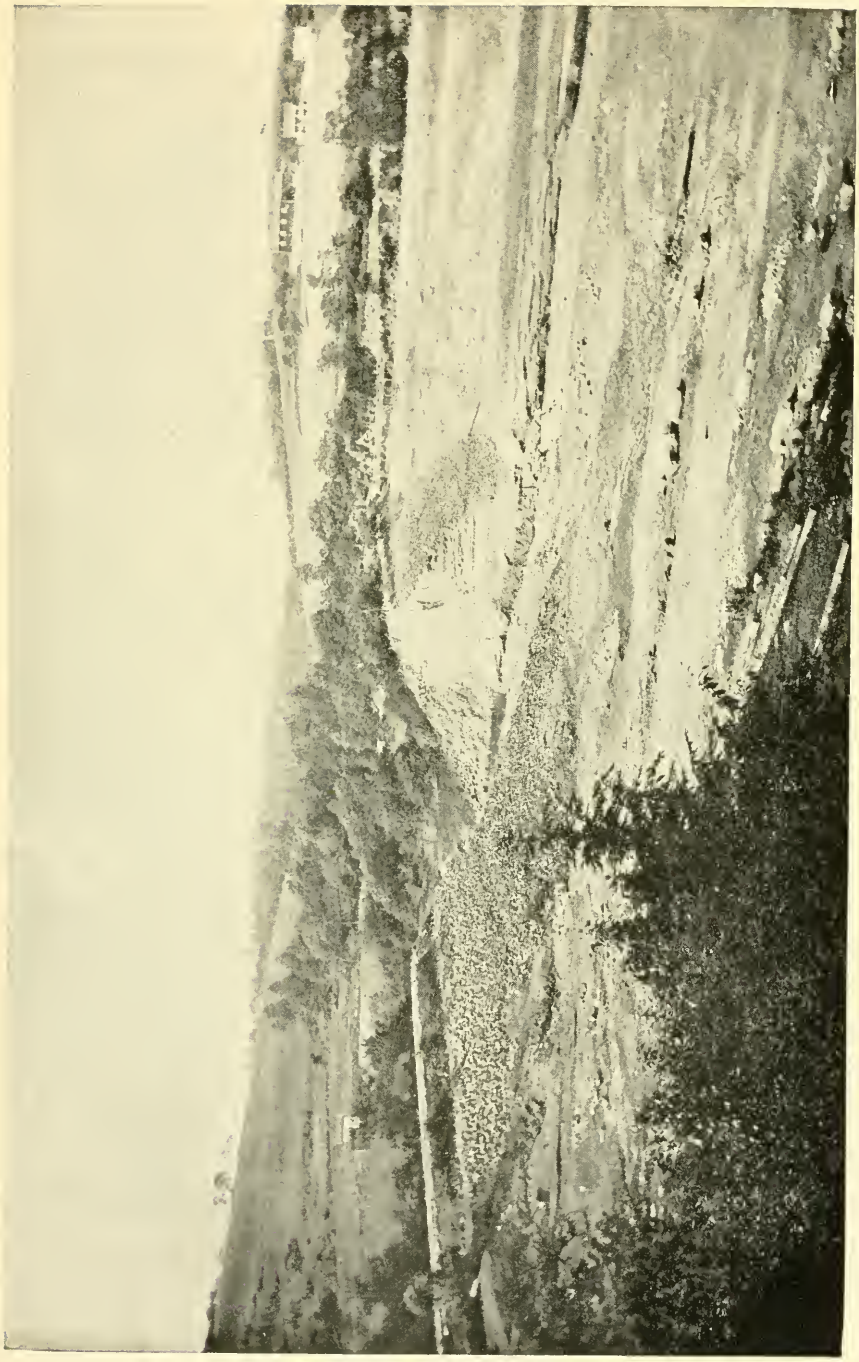
In Plate XLIV the masses of rock shown were portions of the dam which were carried down by the rush of water, but there is evidence that many were brought back to their present position by the strong eddies on each side of the torrent. This is especially remarkable on the west side where the broken trees along the banks show the direction of the flow, and a high reef is formed nearly up to the dam.

The Commonwealth of Pennsylvania in 1834 had constructed and was operating a system of communication from Philadelphia to Pittsburgh, consisting partly of railway and partly of canal, viz.:

Railway from Philadelphia to Columbia.....	82 miles.
Canal from Columbia to Hollidaysburgh.....	172 "
Portage Railway over the Alleghany Mountains from Hollidaysburgh to Johnstown.....	36 "
Canal from Johnstown to Pittsburgh.....	104 "
Total railway and canal.....	394 "

The Canal Commissioners, in their report for 1834, call the attention of the Legislature to the probable failure of the streams to furnish water for the canal during the dry seasons, and caused surveys to be made in order to determine the site of a storage reservoir for the western division of the canal, extending from Johnstown to Pittsburgh. These surveys were made under the direction of Mr. Sylvester Welsh, the principal engineer of the line, during 1834 and 1835. In November, 1835, Mr. Welsh reported a very favorable site for the proposed reservoir, on the south fork of the Little Conemaugh River, and proposed to construct a dam 840 feet long across the valley, which he estimated would create a pool containing about 485 000 000 cubic feet of water. Mr. Welsh proposed a wasteway "at one or both ends of the dam, of sufficient size to discharge the waste water during freshets, and sluices to regulate the supply for the canal." Mr. Welsh estimated that the supply from this reservoir, in addition to the water that flows naturally into these rivers, would supply the water required for the passing of two hundred boats per day, for one hundred and thirty days, without any augmentation from rain.

In April, 1835, the Legislature appropriated $100 000 for various purposes on the public works, among which was mentioned, "The commencement of a reservoir near Johnstown." Under this act Mr. Welsh made further surveys and explorations on Stony Creek and Conemaugh River and their branches, and in his report on the same concludes by recommending a reservoir at the same point as that indicated in his former report. He proposes in this report, a reservoir to cover an area of 465 acres with a content of 525 000 000 cubic feet of water. The plans accompanying the report cannot now be found, but it is gathered from various hints that he proposed to so construct the dam as to give 72 feet depth of water above the bottom of the feeding pipes. In describing the dam, he says: "It is proposed to build the dam of embankment and a wall of masonry in conformity to the plan heretofore submitted. The waste water would be carried through a channel



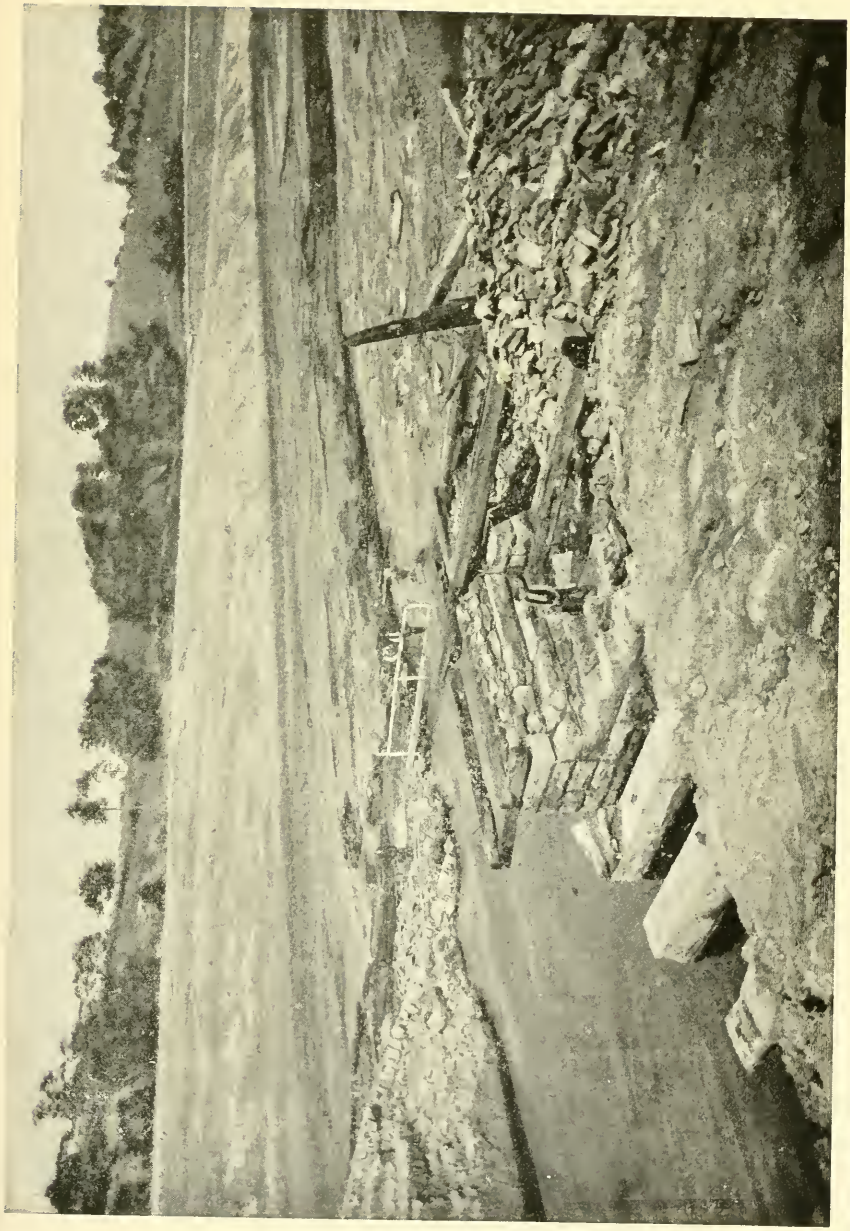
(L. P. de Luze, Phot.) GENERAL VIEW OF THE BROKEN DAM, LOOKING DIAGONALLY ACROSS DAM.

VIEW OF THE BREAK IN THE DAM LOOKING EAST.

(L. P. de Luze, Phot.)

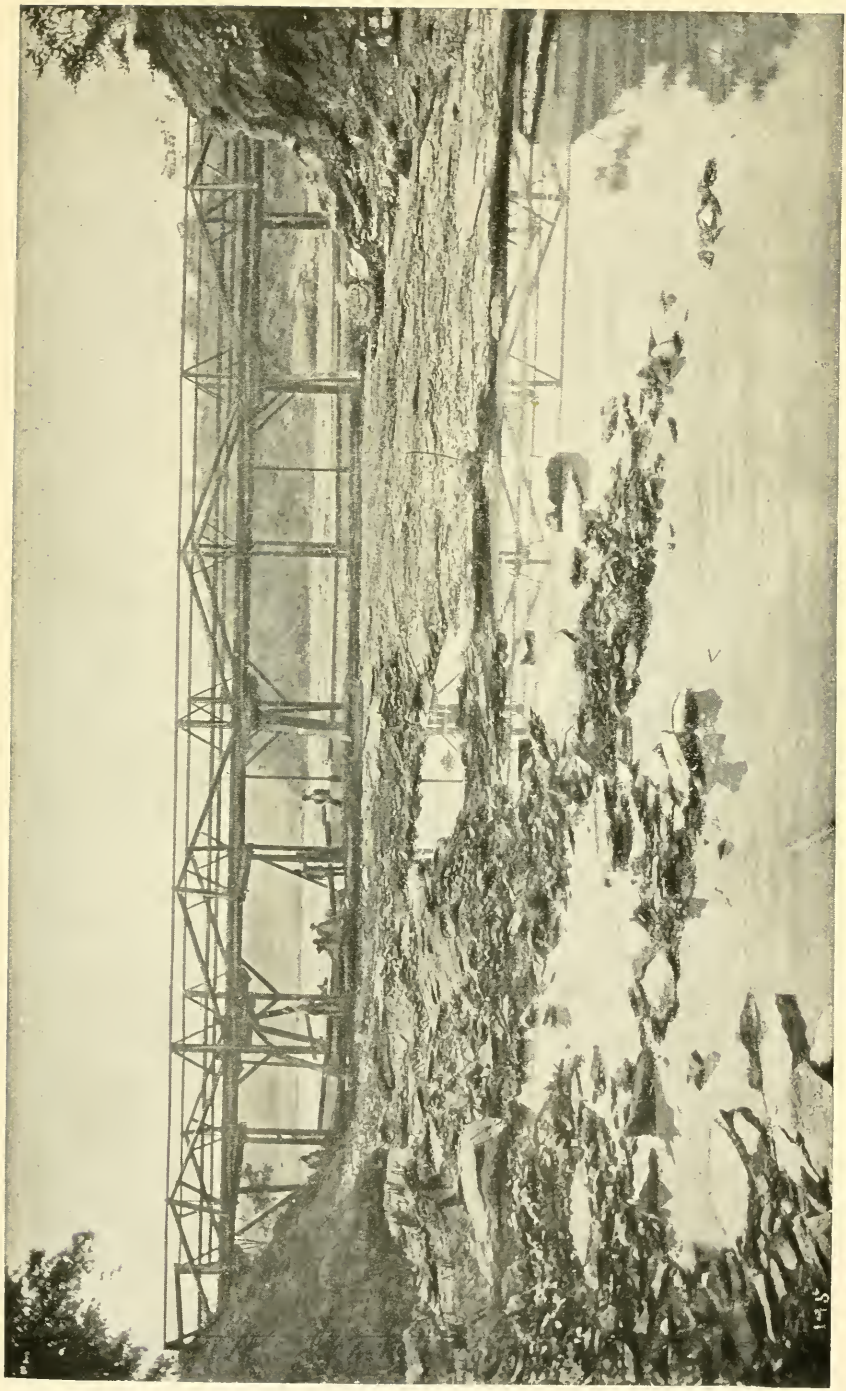
(L. P. de Luze, Phot.) VIEW OF THE BREAK IN THE DAM, LOOKING WEST.

(L. P. de Luze, Phot.) DISTANT VIEW OF BROKEN DAM, LOOKING SOUTH, AND SHOWING STONES LEFT ON THE SIDES OF THE VALLEY BY THE FLOOD.



REMNANTS OF GATE CHAMBER IN DAM.

(L. P. DE LUZE, PHOT.)



(L. P. de Luze, Phot.) VIEW TAKEN FROM A POINT IN THE WATER-WAY, SHOWING BRIDGE AND FISH SCREENS.

to be made round the end of the dam and passed into the ravine below it. The bed of this channel would be solid rock. No water would be permitted to pass over the dam. The sluice through which the water would be drawn from the reservoir when required for use, should be made of cast-iron set in masonry."

The appropriation of $100 000 for this and other works being all required for the "other works," nothing further was done at this time. In the report of the Canal Commissioners for 1838, in reference to the reservoirs on the eastern and western slopes of the mountains, they conclude by saying: "These reservoirs are absolutely necessary, and should be commenced and finished as soon as practicable." In July, 1839, the Legislature appropriated $70 000 for these reservoirs, and the Board placed the work under charge of William E. Morris,* principal engineer, and in their report for the year ending October 31st, 1839, they say the necessary surveys have been completed, the location made and approved by the Board, and the work placed under contract. In his report of November 1st, 1839, Mr. Morris after approving the location of the reservoir as recommended by Mr. Welsh, discusses the character of the dam to be built, whether "a crib dam with a weir upon the top, or an embankment of stone and earth made perfectly water-tight and raised 10 feet above the surface of the pool, having a wasteway or channel cut in the solid rock, at one or both ends of the dam, for the passage of flood water," and decided in favor of the earth embankment. Mr. Morris' original plan is on file in the Department of Internal Affairs at Harrisburgh, and a copy of the same is given on Plate XLVIII. The execution of the work was submitted to public competition, and the construction of the dam was allotted November 6th, 1839, to James Morehead & Co. This was approved by the Board of Canal Commissioners, December 1st, 1839, and David Watson was elected superintendent of the reservoir,

* Mr. William E. Morris was born at Muncy, Lycoming County, Pa., in 1812. In 1839 he was appointed one of the State engineers of the Western Division of the Pennsylvania Canal, and in August of that year he was sent to Hollidaysburgh to take charge of the construction of the South Fork Reservoir Dam and other works on the western division. In the winter of 1842, on account of financial difficulties, the works were suspended, and he, together with other engineers, was discharged. He was subsequently appointed Chief Engineer and President of the Germantown and Norristown Railroad, in 1853 he was appointed President of the Long Island Railroad, and resided in Brooklyn, and was for several years a vice-president of the Harlem Railroad. He subsequently returned to Germantown, where he employed much of his time as a hydraulic engineer, constructing waterworks for the City of Philadelphia; Tenton, N. J.; Wilmington, Del., etc. He died in Philadelphia, October, 1875.

and was authorized to enter into contract accordingly. The cast and wrought-iron work, and the clearing of the land to be flowed, was let to other parties.

The contract with Messrs. James K. Morehead and H. B. Packer, contractors, is dated January 31st, 1840. The prices to be paid are as follows:

Grubbing and clearing, gross sum....	$1 700 00	
Common excavating above water in puddle ditches.....	15	per yard.
Solid rock excavation above water in puddle ditches.....	50	"
Common excavation below water in puddle ditches.....	34	"
Solid rock excavation below water in puddle ditches.....	1 00	"
Slate excavation in wastes.....	32	"
Solid rock excavation in wastes.....	34½	"
Embankment of dam, good earth.. ...	25	"
Embankment of dam, coarse stuff.....	30	"
Puddling.....	38	"
Masonry of sluices.....	6 43	per perch.
Masonry of slope wall.....	1 64	"
Masonry rubble.....	3 93	"
Laying pipe.....	1 00	per lineal foot.

Approximate estimate of work of dam for the Western Division:

Grubbing site of dam, including ground for waste.....	8	acres.
Clearing ground attached to dam.....	5	"
Earth excavation of puddle ditches above water	11 000	yards.
Rock excavation of puddle ditches above water	1 100	"
Earth excavation of puddle ditches below water	2 000	"
Rock excavation of puddle ditches below water	1 000	"
Embankment of dam, good stuff.....	109 000	"
Embankment of dam, slate and stone.....	97 000	"
Puddling.....	2 000	"
Excavation of earth and rock in wastes.....	50 000	"
Vertical wall.....	4 500	perches.
Slope wall.....	6 000	"
Masonry in sluices.....	3 000	"
Laying pipes.....	350	feet.

SPECIFICATIONS OF THE MANNER OF CONSTRUCTING DAM FOR RESERVOIR, ANNEXED TO AND MAKING PART OF THE CONTRACT.

Grubbing and Clearing.

This term is understood to include the removal and burning up of all trees, stumps, logs, roots, leaves, and vegetable matter whatsoever, from a space 20 feet larger in each direction, than that which will be occupied by the dam and wastes, and also from such other places, from which it may be necessary to procure embankment. And in addition to the above, any trees, that in the opinion of the engineer, may be likely to fall into the wastes or upon the dam, shall be felled and burned. About 5 acres of chopping and clearing next above, and adjoining dam, will be included in the contract for dam.

No part of the aforesaid material shall be thrown into the stream, nor shall it be deposited upon the adjoining land, without the permission of the landholders, in writing, endorsed by the engineer. The whole grubbing must be completed before any embankment is made. The quantity of ground attached to western reservoir is about 13 acres. The quantity of ground attached to eastern reservoir is about 10 acres. Timber, scattering. A gross sum will be bid for grubbing the site of dam and ground attached.

Foundation.

After the grubbing is completed, and previous to commencing the embankment, the foundation shall be prepared by removing from the base of the dam, all sod, vegetable matter, and light, porous material, which shall be deposited in such places as may be directed by the engineer, not less than 100 feet outside and below the slope stakes of the embankment.

Puddle ditches shall then be dug, of such depth and width as may be directed by the engineer, and if necessary, sunk to and into the rock. When the stripping is done, and the puddle ditches dug, the whole area so prepared shall be plowed, with deep and close furrows, parallel to the range of the dam.

The Dam

will be constructed as represented in the plan, with a slope of 2 to 1 on the upper side, and 1½ to 1 on the lower side, it will be raised 10 feet above the water line, and be 10 feet on top. The lower angle will be composed entirely of stone, of such nature as to resist the decomposing action of air, frost and water.

In the outer portion of the stone, for 4 feet thick at top and 20 feet thick at bottom, no stone must be used which does not contain at least 4 cubic feet. The remaining part of the stone may be of any size. Next to the stone will be a body of slate rock or coarse gravel 3 feet thick on top, and 30 feet thick at bottom for western, and 20 feet for eastern reservoir.

The remainder of the bank or dam, being that between the water and the slate, shall be composed of the best water-tight, solid and most imperishable material that can be procured, within ¼ mile of the dam. No light, spongy, alluvial, or vegetable matter will be used in its construction. Neither will any coarse gravel or stones larger than 4 inches square be permitted to form any part of it. The whole material of the dam, viz., stone, slate and earth, shall be brought and deposited in the proper place in carts and wagons, and no portion of the dam shall be made by transporting the material in barrows, by schutes, or upon a railway. If it shall be deemed necessary by the engineer, a puddle course of the best fine river gravel, 20 feet in width, shall be carried from bottom of puddle ditch to 4 feet above water line, which said puddle course shall be kept 1 foot higher than the other portions of the embankment, and at all times to be well wet and carted upon, and next the walls, if necessary, well pounded, with a 4-inch rammer. The whole bank shall be made in layers 2 feet thick, be started at the same time, and carried up together, without troughs or hollows, and as nearly level as practicable througout its whole extent. No part of it shall be made in freezing weather. If, during the progress of the work, any part of the embankment, by long exposure or too frequent passage upon it by carts or wagons, shall become so compact upon the surface as to be incapable of uniting completely with the material above to be deposited upon it, such surface shall be well plowed, and, if thought necessary by the engineer, puddle ditches cut, at the expense of the contractor.

In the embankment of the western reservoir, a wall of rubble masonry, made of well-shaped quarried stone, laid in a full bed of cement, with the faces undressed, and the beds and joints close and free from spalls, shall be carried up in the puddle course before-mentioned (or if it be omitted) in the earth embankment. This wall will be started 3 feet below the surface of the rock, if it should be found in excavating puddle ditches, and made completely to fill a trench excavated in the rock for the purpose. It will be 6 feet thick at the bottom, 25 feet high, and 2 feet thick on top; made with buttresses upon each side at intervals of 20 feet, and the difference of thickness between bottom and top, disposed of in offsets of 6 inches in width. No stone shall be used in the wall, of a less size than 2 feet long by 1 foot wide, and 6 inches thick, larger stones to have similar proportions. The wall to be well bound by a system of headers and stretchers so arranged as there shall generally occur one header to two stretchers. The masonry shall be progressed

with as the embankment is raised. Any portion condemned by the engineer shall be immediately taken down and rebuilt.

A slope of wall of dry masonry will be built upon the upper slope of the dam, 15 inches in thickness, backed in by a layer of slate rock or coarse gravel, 6 inches thick. No stone shall be used in its construction which do not reach through the wall, nor any that are of a less size than 4 inches thick by 8 inches wide. This wall shall be neatly laid, the beds of the stone at right angles with the face of the bank, the joints close and free from spalls. A paving of 18 inches depth laid in a similar manner, will cover the top of the embankment.

The cement for the rubble wall and masonry connected with sluices, will be furnished by the Commonwealth, and delivered at the nearest and most convenient point along the line of public improvements, and the contractor will be held responsible for all taken from such places. In working, it shall be mixed while dry with such proportions of clean sharp sand, as the engineer may specify, and the mortar made in small quantities and used immediately. No mortar that has stood over night shall be used in the work. If sand sufficiently clean in its natural state cannot be found, it shall be thoroughly washed.

A waste or waterway will be excavated in the hill at one or both ends of the dam, for the discharge of surplus water in the time of floods, the aggregate width of channels will not be less than 150 feet. The earth covering the rock will first be stripped off, the channel will then be excavated in the rock, leaving for an abutment or guard bank, between the ends of the embankment and the inner slope of the channel, a mass of solid rock, of such width and height, as the engineer may think sufficient. The entrance to the waste or wastes will be as close above the dam as its safety will permit, and its lower termination at least 50 feet beyond the outer slope of the dam.

The material taken from the wastes may be put in its proper place in the embankment of the dam, the stripping of earth upon them will be paid for only as embankment. The slate, detachable rock, and solid rock, found in the wastes will be paid for both as excavation and embankments, except any stone that may be fit for masonry, and used in the walls, which will be paid for only as walls.

Slate rock is such as can be worked with a pick. Detached rock is that which occurs in loose pieces, containing more than 2 cubic feet, and less than 1 cubic yard, or that can be quarried and broken into movable masses without blasting. Solid rock is such as can only be worked by blasting.

Temporary waste weirs, composed of timber and plank, must be constructed by the contractor, at his own expense, at points in the embankment, not more than 15 feet in height above each other, for the purpose of passing with safety to the embankment, any surplus waste water which at any time of high floods, cannot escape through sluices.

Culverts.

The foundations for the culverts or arched way for sluices will be excavated to, and if thought necessary by the engineer, into the rock, which must be suitably leveled for the reception of the walls.

The Masonry

will be range work laid in a full bed of cement mortar, no courses will be less than 8 inches in thickness, nor any stone used in the wall of a less size than 2½ feet long, 16 inches wide and 8 inches thick. The beds and joints of the face stone are to be dressed to a smooth and even bearing 12 inches in width from the face, and brought, when laid, to a joint of not more than ¼ of an inch in thickness. The backing will have the same height as the face stone, the horizontal joints of which shall not exceed ¾ of an inch, nor the vertical joints be at any point more than 2 inches wide, nor shall they average more than 1 inch in width for the length of any joint. All joints shall be broken at least 8 inches.

Both faces of the walls, or the face and back, shall be formed by a regular system of headers and stretchers, laid alternately, and so arranged that the headers upon the front shall be opposite the stretchers on the back.

Both sides of the jambs or abutment walls and both ends of the cross-walls will be considered as face-work. The side walls and ends of the chambers, or entrance of the sluices, both within and without, shall have a rock dress upon the face with a cut draught ¼ inch wide around the edges. Upon the inner sides and ends, the rock dress-work shall not vary from the line or draught more than ½ inch, but upon the outside of the jambs it may be left rough.

The abutment of the part of the culvert below the ends of the pipes, shall be made in the same manner, except the inner face-work shall be picked off to within ½ an inch of variation from the cut draught.

The whole beds or joints of that part of the masonry between the two divisions of the culvert, upon which the pipes are laid, shall be dressed to a smooth even bearing, and so laid as to form joints of not more than ¼ of an inch in thickness. The upper courses shall be 20 inches in thickness and cut to fit the pipes for half their circumference.

If required, a paving shall be placed between the side walls, laid in cement, and in the same manner as the jambs of the culvert. The arch shall be 20 inches in thickness. No stones to be used in its construction, which do not fill the entire depth, are not 18 inches wide, and which do not measure at least 6 inches in thickness on the outside of the arch. They shall be dressed by a pattern to a full bed; the joints not to exceed ¼ of an inch in thickness.

Piling walls or yokes shall be constructed at such points as the

engineer may direct, and the walls of the sluices well united with the vertical wall of dam.

All stone used in the walls must be sound and durable, and approved by the engineer, and materials condemned by him shall immediately be taken to such places as he may direct. That part of the wall exposed to the action of the water, issuing from the pipes, must be made from the hardest and most durable sandstone. Stone more easily dressed may be used in other parts of the work. The mortar will be made as specified for vertical wall of the dam. The lower end of the culvert shall be of neatly cut sand-stone, finished with pilasters and mouldings, as represented in the plan. The parapet and wing walls to be finished with a cut coping of sandstone, 2½ feet in width, securely clamped and leaded. The iron, wrought and cast, the stop-cocks, and fixtures, and lead for joints of pipes, will be furnished by the Commonwealth, and delivered at the site of reservoir, when the contractor will be required to put them in their respective places in the walls.

The wall irons will in all cases be bedded in the stone. The Commonwealth will furnish a force pump to test the pipes, joint by joint, and an experienced machinist to superintend and direct the laying of the pipes, leading the joints, and applying the test, the contractor to put up the force pump and be at all other necessary expenses, for fixtures, hands, etc., to make a secure and perfect job. Any length of pipe or joint that shall prove defective upon the application of a pressure equal to 300 feet head of water shall be taken up and rejected or relaid; proposals will state a price per foot lineal for laying pipes. The culvert walls and pipes to be puddled in such places as the engineer may direct. A suspension way or walk will be constructed from the lower end of the culvert to the stop-cocks at the end of pipes; it will consist of a plankway 2½ feet wide, and 2 inches thick, suspended from the arch of the culvert by iron rods and terminating upon the culvert wing.

A stack of masonry, laid as specified for jambs of culvert, with a rock dress on the faces, will start at the lower ends of chamber as represented in the plan, and be raised to a height equal to that of the dam, finished with a coping of cut sandstone, 12 inches thick and 3 feet wide, securely clamped and leaded; no allowance made for bailing water, coffer dams or other extras.

In the report of the Canal Commissioners of January 1st, 1841, in reference to this reservoir, they state: "It was commenced last spring. The clearing is nearly completed, and the pipe cast and now ready for delivery. All the work at the dam below the surface of the water in the stream, has been done except the sluice walls. If the necessary appro-

priation be made, the work can be completed and brought into use sometime during the next summer." Estimated cost, $188 000.

November 30th, 1841, Mr. W. E. Morris reports: "Since last fall the contractors have steadily pushed on the work at the dam, though, from the smallness of the appropriation, with a moderate force. The sluice walls are raised sufficiently high to receive the pipes, each range of pipe about 80 feet long, has been laid and tested by a head of 300 feet." * * * * "The estimated cost of work done at contract prices is $80 000."

The United States Bank of Pennsylvania, chartered in 1836, with a capital of $35 000 000, intended to take the place of the United States Bank, the renewal of whose charter had been vetoed by the President, finally suspended payment February 4th, 1840. The finances of the State were in such bad condition that the Legislature was forced to curtail its appropriations for the public works to what was absolutely necessary to keep them open for business. April 3d, 1841, an act was passed appropriating $50 000 to pay for all work done on the eastern and western reservoirs up to May 1st, 1841. The contractors were paid up in full and the work stopped. January 3d, 1846, $20 000 was appropriated to the western reservoir, and the Canal Commissioners were required to complete it with as little delay as possible. William E. Morris was called upon to prepare new plans and specifications to be exhibited at a letting on March 3d, 1846. They were the same as those prepared by him in 1839, except that a frame tower was substituted for one of masonry. The former contractors still claimed the right to complete the dam under their contract of 1840. The Canal Commissioners, on account of the large expenditures required to repair the damages by the flood of the spring of 1846, postponed the work, and the appropriation reverted to the general fund and could not be expended without another appropriation. The appearance of cholera in 1848 and its continuance through 1849, caused a general derangement in the business of the country, and it was not until 1850 that a new appropriation of $45 000 was made by the State, and Messrs. Morehead & Packer were permitted to proceed with the work under their original contract. From delay, however, this appropriation reverted to the general fund, and a new appropriation of the same amount was made April 15th, 1851.

The work was commenced May 1st, 1851, and prosecuted as rapidly as practicable. May 4th, 1852, $55 000 was appropriated for the completion of the work, which in the meantime had so far advanced that on June 10th, the sluice gates were closed, and by the end of August water had accumulated in the pool to the height of 40 feet above the feeding pipes. At that time the water in the canal began to fail, and in order to meet the requirements of navigation, the supply in the reservoir was drawn and found ample to keep the canal in full operation until the dry season was over. The embankment of the dam being new, is was deemed

unsafe to fill the reservoir to a greater height than 50 feet above the feeding pipes for the season of 1853, and this season being an uncommonly dry one, the supply of water in the reservoir became exhausted before the close of the season. The contractors seem to have completed the work on the reservoir some time early in the season of 1853. The entire expenditure up to that time, as nearly as can be ascertained, was $166 647.50. During the year 1854, there were two breaks which the Commissioners reported as slight and promptly repaired, but without giving their location or nature.

The canal continued to be operated by the Commonwealth until July, 1857, when it, with the western reservoir, was sold to the Pennsylvania Railroad Company. After it came into their ownership, leaks occurred where the feeding pipes entered the culvert, and finally, in July, 1862, there was a serious break at this point, which washed out the upper end of the culvert and part of the embankment of the dam. About 20 feet of the lower end of the culvert, and the embankment over it remained. The reservoir at this time was only partially filled, and the discharge from the breach passed through the remains of the culvert and was comparatively slow, requiring the greater part of a day to empty the reservoir. The damage caused by it on the stream below, as we are informed, was limited to the washing away of a portion of the embankment of the Pennsylvania Railroad at the eastern end of the bridge over South Fork. In the report of the Chief Engineer of the Pennsylvania Canal to the Pennsylvania Railroad Company, dated January 1st, 1863, it is stated that "the western reservoir dam gave way in July last from a defect in the foundation of the culvert. It is not proposed to repair this work, as an early abandonment of the upper western division is in contemplation."

In the annual report of January, 1864, the Chief Engineer stated that "The upper Western Division, extending from Johnstown to Blairsville, was abandoned as a navigable canal on May 1st last, since which time it has not been kept open." In March, 1875, the property, consisting of about 500 acres of land, including the site of the reservoir, was sold to Mr. John Reilly, who conveyed it to the South Fork Hunting and Fishing Club of Pittsburgh, in June, 1880. In April, 1880, the work of repairing the breach in the dam of July, 1862, was commenced by the Hunting and Fishing Club. It was let out by contract to Colonel B. F. Ruff. The five lines of 24-inch sluice pipes were taken out, the masonry on which they were laid and the remains of the culvert were left. A sheet piling of plank was put across the lower part of the breach. The original plan of making the lower angle of the embankment of stone was adopted, and stone of as large size as could

be obtained in the vicinity were dumped into the breach, letting them form natural slopes. This stone embankment was carried up until it reached such a height as to enable a road to be graded down from the crest of the remaining parts of the dam on each side of the breach, so that material could be hauled in carts from the borrow-pits on the hill side. There being no sluices for the discharge of the flow of the stream, the surplus water found its way through the stone embankment, the water in the reservoir rising as the filling on the upper side of the stone embankment proceeded. The washing of the filling through the stone embankment was prevented by covering its face with brush, hay, etc. The material relied on to form the water-tight embankment consisted of clay and shale, which was dumped in on the upper side of the stone embankment, and carried up in layers to the full width of the remaining parts of the original dam. There was no systematic puddling done, but the hauling by teams over the freshly deposited material, which was kept wet by the rising water, made a fairly compact embankment on the upper side of the stone embankment. The work was not completed that season, and during the following winter it was damaged by a flood, and the next year, 1881, the Hunting and Fishing Club completed it by day work. The slopes on both sides of the embankment were covered with a heavy rip-rap.

According to Mr. Morris' original plan and specification the top of the dam was 10 feet wide and 10 feet above the ordinary surface of the water in the reservoir, which is understood to be nearly the same as the floor of the wasteway. By our levels the floor of the wasteway for 176 feet from the lake averages 1602.82 feet above tidewater. The elevation at eight points on the top of the remaining parts of the dam, where not affected by the late washout is 1610.78 being 7.96 feet above the floor of the wasteway, or 2.04 feet below its height as originally designed. This accords substantially with the statements of parties living in the vicinity, to the effect, that when the breach was repaired in 1880–81, the top of the dam was lowered about 2 feet in order to make a more convenient roadway over it, the remains of which are now 15 to 20 feet wide.

On May 30th, 31st and June 1st, 1889, there was a great rain on an area of about 20 000 square miles, mostly in Pennsylvania, but extend-

TABLE No. 1.

Observations of the Rain-fall on Thursday, May 30th, and Friday, May 31st, 1889, at Stations within a radius of fifty miles from the center of the Water-shed of the South Fork Reservoir. Collated from the Records of the United States Signal Service and the Pennsylvania State Weather Service, as published in their respective Monthly Reviews for May, 1889.

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Station.		Quarter, and Approximate Direction and Distance of the Station from the Center of the Water-shed.			Rain-fall by United States Signal Service.					Rain-fall by Pennsylvania State Weather Service.					Average rain-fall in the two days. Inches.	Remarks.
							Rain Fall.					Rain-fall.				
Place.	County.	Quarter.	Direction.	Distance, Miles.	Time of Beginning.	Time of Ending.	Thursday, May 30th. Inches.	Friday, May 31st. Inches.	Amount in the two days. Inches.	Time of Beginning.	Time of Ending.	Thursday, May 30th. Inches.	Friday, May 31st. Inches.	Amount in the two days. Inches.		
Grampian Hills	Clearfield	North-east.	N. 6° E.	45	30th, 4.30 P.M.	31st, 11.20 P.M.	0.23	8.37	8.60	30th, 11.40 P.M.	31st. 11.20 P.M.	0.23	8.37	8.60	8.60	From 11.40 P.M., May 30th, to 11.20 P.M., May 31st, 8.37 inches of rain. Six inches of rain fell in seven hours.
Phillipsburgh	Centre	"	N. 32° E.	47	30th, 3.50 "	.....	....	2.83	2.83	.....	.....	...	2.83	2.83	2.83	
Tipton	Blair	"	N. 46° E.	28	30th, 4.00 "	.....	0.80	3.36	4.16	30th, 3.00 P.M.	.....	....	....	....	4.16	
Altoona	Blair	"	N. 50° E.	21	30th, 3.30 "	.....	....	3.03	3.03	30th, 4.00 P.M.	.....	....	....	....	3.03	From 9 P.M., May 30th, to 9 P.M., May 31st, 6.12 inches of rain
Hollidaysburgh	Blair	"	N. 64° E.	16	30th, 8.00 "	31st, 12.00 P.M.	2.11	3.99	6.10	.....	.....	0.39	5.12	5.51	5.80	
Petersburgh	Huntingdon	"	N. 66° E.	38	30th, 3.00 "	31st, 11.60 P.M.	0.01	6.60	6.61	30th, 4.00 P.M.	.....	....	....	....	6.61	
Huntingdon	Huntingdon	"	N. 74° E.	39	30th, 4.00 "	.....	0.60	4.22	4.82	.....	.....	....	....	....	4.82	
Blue Knob	Blair	"	N. 84° E.	12	.....	.....	....	7.90	7.90						7.90	
															6.47	Average rain-fall in north-east quarter.
McConnellsburgh	Fulton	South-east.	S. 55° E.	48	.....	.....	1.23	7.08	8.31	30th, 4.00 P.M.	31st, 12.00 P.M.	1.23	7.08	8.31	8.31	6.45 inches of rain from 4.00 P.M., May 30th, to 4.00 P.M. May 31st. 8.31 inches of rain in 32 hours.
Charlesville	Bedford	"	S. 24° E.	29	.....	.....	0.61	6.71	7.32	30th, 3.16 P.M.	.....	0.61	6.71	7.32	7.32	
															7.81	Average rain-fall in south-east quarter.
Somerset	Somerset	South-west.	S. 42° W.	28	30th, 10.00 P.M.	31st, 10.00 A.M.	....	4.43	4.43	.....	.....	....	....	....	4.43	
Greensburgh	Westmoreland	"	West.	42	30th, 8.00 P.M.	.....	....	1.70	1.70	.....	.....	....	....	....	1.70	
															3.06	Average rain-fall in south-west quarter.
Johnstown	Cambria	North-west.	N. 80° W	9	.....	.....	....	....	....	.....	.....	....	....	....	....	Rain-gauge carried away by the flood at 10.44 A.M., May 31st. Not more than three-fourths of the rain-fall in the Johnstown Valley had fallen up to 3 P.M. on the 31st.
Saltsburgh	Indiana	"	N. 70° W.	40	.....	.....	....	1.94	1.94	.....	.....	....	....	....	1.94	
Indiana	Indiana	"	N. 45° W.	32	30th, 2.00 A.M.	31st, 7.30 P.M.	2.00	1.00	3.00	.....	.....	....	....	....	3.00	
															2.47	Average rain-fall in north-west quarter.

ing into Maryland, Virginia and West Virginia. It is estimated that about three-fourths of this area, or 15 000 square miles, constituted the flooded area in Pennsylvania; the greatest amount of water appears to have fallen near the summit of the Alleghany Mountains and a little east of the same, where the rain-fall was reported to have been 8 to 10 inches in eighteen to thirty-six hours. Official records of the rain-fall are reported from about fifty stations, but there is none from any point on the water-shed of the South Fork Reservoir, and it can only be inferred from the observations reported from other water-sheds in the vicinity. To enable this to be done approximately, the observations reported from stations within 50 miles of the center of the water-shed of the South Fork Reservoir (see Plate LIX) are collected in the annexed Table No. 1. As will be seen, the stations are limited to the area of a circle of 100 miles in diameter having its center in the center of the South Fork water-shed, and they are arranged according to the quarter of the circle in which the station is situated. The results are as follows:

In the northeast quarter,	average	rain-fall....	5.47	inches.
" southeast	"	"	"	7.81	"
" southwest	"	"	"	3.06	"
" northwest	"	"	"	2.47	"

The northeast and southeast quarters include parts of the summits of the Alleghanies and of their eastern slopes. The easterly boundary of the South Fork water-shed is this summit, and by inspection of the table and the accompanying map, we infer that the rain-fall on this water-shed was from 6 to 8 inches. As we are informed, the heaviest part of the rain was during the night of May 30th, and 31st, during which time it appears that there must have been several hours when it fell at a rate of not less than two-thirds of an inch an hour on this water-shed. By the survey of the water-shed above the dam, made for us by Mr. A. Y. Lee, civil engineer of Pittsburgh, its area is 48.6 square miles. (Plate XLVII is a reduced copy of his map.)

Mr. John G. Parke, Jr., civil engineer, had been employed for about two months previous to the disaster in improving the drainage of the property of the South Fork Hunting and Fishing Club, and was residing at their club house situated on the southerly shore of the reservoir about three-quarters of a mile from the dam. Mr. Parke has

kindly furnished us with an account of his observations and experience on the day of the failure; we do not undertake to condense it, but give it in full as the best account we have been able to obtain.

M. J. Becker, Esq.,
President Am. Soc. of C. E.:

Dear Sir,—Being requested by your Committee to give an account of the destruction of the South Fork Dam, I will do so by narrating my experience of the affair and the few observations I made at the time.

On the evening preceding the destruction of the dam, to the best of my recollection, we had many evidences of an approaching storm, and when it grew dark, we had a violent wind storm, and the tree tops about the house were moaning and creaking unusually, but no rain fell. About 9 o'clock I had occasion to go out of the house a short distance and noticed that the board walk was wet and that there had been a slight rain-fall, but it was not raining at the time, and the sky was much brighter and evidently clearing off, but there was still a high wind blowing. These sudden, violent wind storms, very often accompanied by heavy but brief rain-falls, were customary in that mountainous country, as I had noticed during my two months' location at the lake previous to this time.

I retired shortly after 9 o'clock and slept very soundly, awaking once towards morning and hearing a heavy rain. When I awoke at about 6.30 on the morning of the 31st, I found it very foggy outside, and on going out, found the lake had risen during the night probably 2 feet, and I heard a terrible roaring as of a cataract at the head of the lake, about a mile above the club house where I was staying. After eating breakfast and returning to the shore I found the lake had risen appreciably during our absence, probably 4 or 5 inches, and with difficulty secured a boat, and with a young man who was employed on some plumbing work at the cottage, I rowed to the head of the lake to see the two streams that were pouring into the lake with such an unusual roar. I found that the upper one-quarter of the lake was thickly covered with debris, logs, slabs from sawmill, plank, etc., but this matter was scarcely moving on the lake, and what movement there was, carried it into an arm or eddy in the lake, caused by the force of the two streams flowing in and forming a stream for a long distance out into the lake. The lake seemed very high when I reached the head, for we were able to row over the top of a four-wire barbed fence which stood near the normal shore line and we rowed for 300 feet across a meadow which was covered with water, for it was very flat and a rise in the lake of a foot, covered a large area. I did not get very near to one stream (the Muddy Run), but could see the volume it was pouring in by its current in the still water, but we did go up the shores of the South Fork Creek and found it widely overrunning its banks. In its normal condition it is

about 75 feet wide and barely 2 feet deep—many places not that deep, but varying as every mountain stream does. But on this day it was a perfect torrent, sweeping through the woods in the most direct course, scarcely following its natural bed, and stripping branches and leaves from the trees 5 and 6 feet from the ground. We tramped through the fields adjoining the woods in which the stream was boiling, for a half mile above its mouth and could appreciate its volume and force, for I was familiar with the region and saw where the stream covered a portion of the township road for a depth of 3 feet, which is never covered except in floods. Returning to our boat, we found it almost adrift, the water having risen during our absence. We rowed to the club house and found the water had risen at a wonderful rate during our row to the top of the lake. I had been thinking of the dam and was not surprised when landing to be told that the water was nearly over the dam and that men and a plow were needed there. So taking a horse from the stable, I rode to the breast and found Colonel Unger, President of the South Fork Fishing and Hunting Club at work on the dam with a number of Italian laborers (that we had employed on some sewerage work); there were about sixteen of them. Half of them were cutting a ditch through the shale rock at one end of the breast. This ditch was cut through the original ground and about 25 feet from the constructed portion of the breast. The shale was so tough that they could not cut it more than about 14 inches deep and about 2 feet wide, but when it was cut through to the lake, the water rushed in and soon made it a swift stream, 25 feet wide and about 20 inches deep, but the rock was so hard that it could not cut it any larger than this. Previous to this being opened and shortly afterward, I made two observations of the height of the water, and the lake in the hour had risen 9 inches. During the digging of this ditch, I rode back and forth over the dam directing the laborers. We had a plow at work throwing up a furrow, and thus raising a temporary barrier or breast to retard the water flowing over the dam, should it reach that height which it was gradually doing. I noticed that the waste-weir proper was discharging to its full capacity, and that there was no drift or other matter to clog it, except a road bridge supported on small posts which were apparently offering but little resistance as the weir was narrower by about 15 feet at 100 feet from its mouth, and this contraction compensated for the resistance to flow offered by the bridge supports. There was probably 7 feet of water in the weir at the time. There were some iron screens between the foot of each post on the outer row of the bridge supports, but they were but 18 inches high and could not have been removed, had we wished to, owing to the depth and velocity of the water. The water in the lake rose until it was passing over the breast, notwithstanding that the lake had then the two outlets (the waste-weir and the one cut by the laborers). The breast was slightly lowered in the center and the water

washed away our temporary embankment thrown up by the plow and shovels, and the water was passing over in many places in a distance of 300 feet about the center of the breast; the men stuck to their task and worked until the water was passing over in nearly one sheet, and then they became frightened and got off the breast. I saw what would be the consequence when the water passed over the breast and rode to South Fork Village and warned the people in the low lands there, and had word telegraphed to Johnstown that the dam was in danger. The people in South Fork heeded the warning and moved out of their houses. When I left South Fork to return it was just twelve o'clock noon, and the water had been flowing over the dam for at least a half hour. I rode back up to the lake 2½ miles through the valley and found the men had torn up a portion of the flooring of the waste-weir bridge and were endeavoring to remove the V-shaped floating drift guard that projected into the lake. It was a light affair and was built to float on the surface of the lake and catch twigs, leaves, etc., and prevent their clogging up the iron screens spoken of above. I crossed the breast at this time and found the water was cutting the outer face of the dam, but not as badly as I feared it would, its greatest effect was on some portions of the roadway which crossed the breast where the roadway had been widened on the lower side by the addition of a shale earth or disintegrated shale, upon which the action of the water was instantaneous, but the heavy rip-rapping on the outer face of the dam protected this wash and the water cut little gullies between each of the large stones for rip-rap. I did not stay on the dam when it was in that condition, but went on to the end of the dam and found that over its entire top it was serried by little streams where the water had broken through our little embankment and was running over the dam. I went on to the new waste-weir we had cut and found it carrying off a great volume of water and at a great velocity. I with difficulty waded it and found that it was up to my knees or 20 inches deep. I felt confident that nothing more could be done to save the dam unless we were to cut a wasteway through the dam proper at one end and allow it to cut away in but one direction, and that towards the center of the dam, but this I would not dare to do, for it meant the positive destruction of the dam, and the water at the time was almost at a stand, owing, without doubt, to the large increase of outlet by the overflow on the breast, and I hoped that it would not rise, but yet expected it to rise for it had been raining most all of the morning, and consequently we had more water to expect. I hurried to the club house to get my dinner and to note the height of the water in the lake, and found that it was a little over a stake, that from my level notes of a sewer I was constructing I knew was 7.4 feet above the normal lake level. I returned to the dam and found the water on the breast had washed away several large stones on the outer face, and had cut a hole about 10 feet wide on the outer-

face and about 4 feet deep, the water running into this hole cut away the breast in the form of a step both horizontally and vertically, and this action went on widening and deepening this hole until it was worn so near to the body of the water in the lake that the pressure of the water broke through, and then the water rushed through this trough, and cut its way rapidly into the dam at each side and the bottom; and this continued until the lake was drained. I do not know the actual time it consumed in passing through the breach, but it was fully 45 minutes. It did not take long from the time that the water broke into this trough until there was a perfect torrent of water rushing through the breast, carrying everything before it, trees growing on the outer face of the dam were carried away like straws. The water rushed out so rapidly that there was a depression of at least 10 feet in the surface of the water flowing out, on a line with the inner face of the breast and sloping back to the level of the lake about 150 feet from breast, exactly similar to water flowing through a rectangular sluice-way in the side of a trough with the water level far above the bottom of the sluice-way. When the lake was drained there still remained in the bed of it a violent mountain stream 4 or 5 feet deep, with a swift current, the combination of the two streams already alluded to from the head of the lake and the many little streams from the adjacent hills, which streams were all overflowing their banks, this stream in the bed of the lake showed no signs of diminishing in volume until late in the following day, and was impassable with a boat for several days.

I need say nothing of the character of the dam, for it is open for inspection of those far more able to express an opinion than I. But there is one thing I want to impress on every one's mind, and that is, that the dam did not break, but was washed by the water passing over it from 11.30 o'clock A.M. until nearly 3 P.M. until the dam was made so thin at one point, that it could not withstand the pressure of the water behind it, and the water once rushing through this trough nothing could withstand it.

Hoping this report will be of some service to your Society, and placing myself at your disposal to answer any inquiries as to the destruction of the dam or any points that I have not developed, believe me, Respectfully yours,

JOHN G. PARKE, Jr.

AMERICUS, Ga., August 22d, 1889.

By the survey of the reservoir made for us by Mr. William H. Scriven, its area at the ordinary height of the water was 407.4 acres. At 5 feet above the ordinary height, 456.8 acres. On account of the obstruction at the head of the wasteway caused by the fish guard, and the sill on which it was placed, the ordinary height of the water in the

reservoir must have been about a foot above the average height of the floor of the wasteway.

Mr. Parke's observation of the rise of the water in the reservoir of 9 inches in an hour, combined with the area of the reservoir, enables us to compute the rate of accumulation of water in the reservoir just before it commenced running over the embankment. To find the rate at which the water was flowing into the reservoir at the same time, it is necessary to ascertain the rate at which it was flowing out through the wasteway. This is a more uncertain matter, as we have been unable to find any rule or principle of hydraulics directly applicable to the case. We have, however, attempted to approximate to it by three methods which we have worked out separately, and give in some detail in the appendix to this report. The second method, being founded more directly on experiment, we have most confidence in, and adopt.

Mr. Parke's observation of the rise of 9 inches in an hour was evidently made when the height in the reservoir averaged about 7½ feet above the floor of the wasteway. At this height the area of the reservoir was 471.62 acres, and the accumulation was at the rate of

$\frac{471.62 \times 43\,560 \times 0.75}{60 \times 60}$	4 280	cubic feet per second.
By our second method the discharge through the wasteway at this height was	3 700	" "
Total quantity entering reservoir at 11.30 A.M.	7 980	" "

Earlier in the day, say at 10 A.M., the rise in the reservoir was probably more rapid, it was currently reported to have been 10 inches an hour. There is no probability that it exceeded 12 inches an hour. At that rate, when the height in the reservoir was 5 feet above the floor of the wasteway, the accumulation would have been at the rate of

	5 408	cubic feet per second.
Discharged through wasteway by our second method	1 800	" "
Total quantity entering reservoir	7 208	" "

Just previous to the breach in the embankment the water was flowing over a large part of its length. From the statements of Mr. Parke

and others who saw it, we gather that the flow was equivalent to 100 feet in length 1 foot deep, and 300 feet in length 9 inches deep. We estimate the quantity flowing over at

	991	cubic feet per second.	
The accumulation in the reservoir we estimate to have been 6 inches in depth in the last hour, equivalent to.....	2 911	"	"
The discharge through the wasteway when the height in the reservoir was 8.71 feet above the floor of the wasteway by our second method was.....	4 780	"	"
Estimated flow into the reservoir at the commencement of the breach, say at 0.45 P.M.....	8 682	"	"

These three estimates of the flow into the reservoir indicate that it increased up to the time of the breach, and no doubt continued to do so for some time longer. Two-thirds of an inch of rain per hour on the water-shed is equivalent to 20 909 cubic feet per second. The rate of flow caused by a given rain-fall from any water-shed, in the absence of direct measurement is always difficult to estimate; it depends on several conditions:

First.—The length of time during which the rain-fall at any given rate has continued, it being obvious, that the longer it continues the nearer the rate of flow from the water-shed will approximate to the rate of the rain-fall.

Second.—The extent of the water-shed; the larger it is, the longer will be the average time required to reach the reservoir.

Third.—The general inclination of the surface, on which depends the rapidity of the flow from the water-shed.

Fourth.—The character of the water-shed as to its capacity to hold back the water; the favorable conditions for discharging rapidly being rocky and cleared surfaces; and for discharging slowly; ponds, lakes, swamps, large level tracts and woodland.

In this case the extreme length of flow does not exceed 10 miles, and the average length probably is less than 4 miles. The inclination of the

surface and the character of the water-shed appear to be generally favorable to a large discharge, and taken in connection with the continuance for several hours of heavy rain-fall, it would appear that a maximum rate of flow into the reservoir of one-half the rate of the rain-fall would not be too large an estimate. This would give a flow into the reservoir for a rain-fall of two-thirds of an inch an hour of $\frac{20\,909}{2} = 10\,454$ cubic feet per second.

This considerably exceeds the estimates of the flow just previous to the breach, but is not inconsistent with it as a maximum. Mr. Parke's observation just before the commencement of the breach, that "it had been raining most all of the morning and consequently we had more water to expect," and on the strong current in the bed of the lake immediately after the breach, and its long continuance subsequently, indicate a possible increase of the flow to this extent. The accompanying diagram, Plate LII, of the estimated flow into the reservoir during the storm, indicates that if the maximum flow was 10 000 cubic feet per second, it would occur at about 4 P.M. of May 31st, or about three hours after the breach; but we have no proof that it would not have been later and the maximum flow correspondingly larger.

The breach in the embankment is about 420 feet wide at the top and 50 to 200 feet wide at bottom, the amount of earth and stone in the same being about 90 000 cubic yards, Plate L. All the material put in in 1880 and 1881, to repair the breach of 1862, appears to have been washed out, together with part of the old embankment made in 1851 and 1852. Some parts of this old work are exposed by the flood, and indicate that it offered great resistance to washing and that it was originally selected and put in with the requisite care to make a sound embankment. The original construction of the embankment as indicated by the plan and specification, and more particularly the mode of repairing the breach, may be objected to as not being according to the best practice; nevertheless, the failure of the dam cannot be attributed to any defect in its construction. The failure was due to the flow of water over the top of the earthen embankment, caused by the insufficiency of the wasteway to discharge the flood water.

Recapitulating, briefly, what we have ascertained relating to the wasteway: In 1835, Mr. Sylvester Welsh, then principal engineer of the Canal Commissioners, recommended the site for the dam and proposed a wasteway at one or both ends of the dam of sufficient size to discharge the water waste during freshets and stated that "no water would be permitted to pass over the dam." In a report dated November 1st, 1839, Mr. William E. Morris, then principal engineer, recommends for the dam an embankment of stone and earth having a wasteway at one or both ends of the dam for the passage of flood water, and in the specification prepared by him for the execution of the work which was let out by contract in 1839, it was provided that the wasteway excavated in the hill at one or both ends of the dam, shall have an aggregate width of channel of not less than 150 feet. Little progress was made on the work until 1846, when Mr. Morris, although no longer in office as the principal engineer of the Canal Commissioners, was called upon by them for plans and specifications for a new letting. They were the same as those prepared by him in 1839, except that a frame tower was substituted for one of masonry. Nothing appears to have been done until 1851, when the work was proceeded with and completed in 1853. The wasteway was, however, not constructed according to Mr. Morris' specification; instead of having an aggregate width of 150 feet, its effective width was less than 70 feet. The width at its entrance, where it is the widest, is about 120 feet, and at the outfall, 176 feet from the reservoir, it is about 69 feet, which must be taken as its effective width. The horizontal bed of the wasteway from the reservoir to the outfull, a distance of about 176 feet, sensibly diminished its efficiency, over what it would have been if the outfall had been at the entrance of the wasteway.

Assuming the maximum flow into the reservoir to have been 10 000 cubic feet per second, and the wasteway to have been constructed according to Mr. Morris' specification, with a free outfall at the entrance, we estimate that the corresponding height in the reservoir would have been 7.80 feet above the crest of the wasteway, or 2.20 feet below the top of the embankment as specified by him. With the five lines of 24-inch sluice pipes discharging to their full capacity at the same time, under 70 feet head, as no doubt was originally designed to be done in an emergency, we estimate the height in the reservoir would be about 7.52 feet or 2.48 feet below the top of the embankment.

The height of the embankment as constructed in 1851–53, was accord-

ing to Mr. Morris' plan and specification. According to our method of estimating the flow through the wasteway, the discharge through it, when free from obstruction, and the water in the reservoir just up to the top of the embankment as originally constructed, and the sluice pipes discharging to their full capacity, would be 6 923 cubic feet per second. For the wasteway and sluices, as constructed in 1851–53, to discharge 7 980 cubic feet per second, which we have estimated above to have been the flow into the reservoir at the time of the breach, the height in the reservoir under the same conditions would be 10.95 feet above the floor of the wasteway or about 1 foot above the top of the embankment as originally constructed. For the discharge of the maximum quantity entering the reservoir, which we think was not less than 10 000 cubic feet per second, under the same conditions, would require a depth of about 12.63 feet.

The Hunting and Fishing Club, in repairing the breach of 1862, took out the five sluices in the dam, lowered the embankment about 2 feet, and subsequently, partially obstructed the wasteway by gratings, etc., to prevent the escape of fish. These changes materially diminished the security of the dam, by exposing the embankment to overflow, and consequent destruction, by floods of less magnitude than could have been borne with safety if the original construction of 1851–53 had been adhered to; but in our opinion they cannot be deemed to be the cause of the late disaster, as we find that the embankment would have been overflowed and the breach formed if the changes had not been made. It occurred a little earlier in the day on account of the changes, but we think the result would have been equally disastrous, and possibly even more so, as the volume of water impounded was less, and the greater width of the top of the embankment after the change and its consolidation by its use as a road for several years, must have increased its resistance to the formation of a breach and required more time.

In concluding, we must state that, while our deductions are based on the results of observations of rain-fall and of flow which are necessarily approximate, we feel satisfied that they are not far from the truth. There can be no question that such a rain-fall had not taken place since the construction of the dam. But the surface of the water-shed is quite steep, and the consequent rapid discharge of a large percentage of the rain-fall into the reservoir would require a very large outlet to prevent a dangerous accumulation. The spillway, however, had not a sufficient

discharging capacity; contrary to the original specifications of Mr. W. E. Morris, requiring a width of overflow of 150 feet and a depth of 10 feet below crest, which would have been a sufficient size for the flood in the present case, it had only an effective width of 70 feet, and a depth of about 8 feet; the accumulated water rose to such a height as to overflow the crest of the dam and caused it to collapse by washing it down from the top.

The dam itself, or the parts of it which were left standing, showed undoubtedly that it was well and thoroughly built, and that it would have successfully resisted the pressure of the water. The exposed sides of the breaks show distinctly that the compact layers of which the structure was formed were not obliterated by the wearing action of the flood, and they stand conspicuous witnesses of the value of an earth embankment when well built of good materials, to impound large bodies of water.

There are to-day in existence many such dams which are not better, nor even as well provided with wasting channels as was the Conemaugh Dam, and which would be destroyed if placed under similar conditions.

The fate of the latter shows that, however remote the chance of an excessive flood may be, the only consistent policy, when human lives, or even when large interests are at stake, is to provide wasting channels of sufficient proportion and to build the embankment of ample height.

Respectfully submitted,

James B. Francis,
W. E. Worthen,
M. J. Becker,
A. Fteley.

January 15th, 1890.

APPENDIX.

Estimates of the Discharge through the Wasteway and Sluice Pipes.

The wasteway of the South Fork Reservoir in plan, is about 120 feet wide at the reservoir, narrowing to about 67 feet at 176 feet from the reservoir, the axis being nearly a quadrant of a circle of about 100 feet radius. In profile the average level of the bed of the wasteway for 176 feet

from the reservoir is nearly horizontal (see Fig. 4, Plate XVI). The noted elevations varying from 0.14 feet above the average to 0.08 feet below. In the next 50 feet a descent of a foot is noted. This is evidently amply sufficient to maintain the velocity acquired by the water at the end of the horizontal part of the said bed, and consequently the bed beyond this point offers no resistance to the flow over the horizontal part, and this point is therefore taken to be the outfall of the wasteway.

To compute the discharge through a wasteway of this peculiar form we have not found any formula or established principle in hydraulics that will enable it to be done directly. The three following methods of approximating to it occur to us, which we have worked out separately, viz.:

First Method.

In the first place it is assumed that the bed offers no resistance and that the flow adjusts itself so that the discharge is a maximum, which we find is when the descent of the surface of the water from the reservoir to the outfall, is one-third and the depth of the stream at the outfall two-thirds of the height of the water in the reservoir above the bottom of the wasteway. This is based on the idea that the velocity at the outfall is that due to the descent of the surface $\frac{D}{2}$, and that this applies to the whole depth of the stream D. The assumed height in the reservoir being $1.5D$.

In working this out it is assumed that the velocity through the section of the stream at the outfall is that due to the head $\frac{D}{2}$ with a coefficient of contraction of 0.9, and the discharge Q is the product of this velocity into the area of the section at the outfall.

To find the real height in the reservoir, there must be added to the assumed height $1.5D$ a head equivalent to the resistance of the bed when the quantity, computed as above, is flowing. This is done by means of the Chezy formula: $V = 75\sqrt{RI}$, from which we deduce for the channel 176 feet in length, putting $H =$ the required head and $R =$ the hydraulic mean depth.

$$H = \frac{0.0313\ V^2}{R}.$$

To allow for the variations in the width and depth of the wasteway (see Sec. 1, Plate XLI) we determine V^2 and R for the several sections of the channel and take their mean values. As H is a factor of V and R at each section, we arrive at the result by successive approximations. The height in the reservoir corresponding to the computed discharge for the depth R at the outfall is $1.5D + H$.

The above computation is for the case where there is no obstruction at the entrance of the wasteway. When obstructed by the fish-guard

and posts supporting the bridge, as it was when the dam gave way, an addition to the height must be made equivalent to the obstruction. The top of the fish-guard is understood to be 2.14 feet above the bottom of the wasteway, and the area of the obstruction to this height, including the posts supporting the bridge to the same height, we find to be 120.43 square feet. Above the top of the fish-guard the posts supporting the bridge were the only obstructions, and for each foot in height they add 7.9 square feet, and for any height H^1 in the reservoir greater than 2.14 feet, the area of the obstruction is $120.43 + 7.9\ (H^1 - 2.14)$ square feet.

To find the additional height due to the obstruction, the area obstructed is subtracted from the total area of the section at the entrance of the wasteway, the difference being the area through which the water enters the wasteway, and the velocity found for each area and also the heads due these velocities. In computing them a co-efficient of contraction 0.9 is used for the unobstructed section and from 0.6 to 0.8, depending on the height in the reservoir for the obstructed section. The difference in these heads $h^1 - h$ is the addition to be made to the height in the reservoir corresponding to the discharge, the total height being $1.5D + \mathrm{H} + h^1 - h$.

Second Method.

The discharge is considered to be over a weir or dam with a wide crest. Experiments were made at Lowell, in 1852, and are recorded in Lowell Hydraulic Experiments, on such a dam in which the crest was about three feet wide, in this case it will be 176 feet wide, and to give the height in the reservoir it is necessary to add to the depth at the outfall a head equivalent to the resistance to the flow over this width of crest. The formula given with the record of the experiments is determined from the discharge with depths from 0.59 feet to 1.63 feet. As being better adapted to the present purpose, the formula is determined anew from the experiments in which the depths are 1.32 feet and 1.63 feet, from which we find $Q = 3.056\ L\ H^{\frac{3}{2}}$ in which L is the effective length of the weir, and is obtained by dividing the area of the section at the outfall by the depth H. The additional height in the reservoir equivalent to the resistance to the flow over the wide crest is determined in the same manner as the head equivalent to the resistance of the bed in the first method, and the additional head when the entrance to the wasteway is obstructed by the fish-guard, etc., is determined in the same manner as in the first method.

Third Method.

It is assumed that the discharge is through an orifice converging laterally, but of a uniform height, the same as the depth at the outfall, the orifice being of the same area as the section of the stream at that

point, with a velocity due to a fall equal to one-half the depth at that point, computed with a co-efficient of contraction of 0.9, and to find the corresponding heights in the reservoir, the heads, equivalent to the resistance of the bed and to the obstruction, if any, at the entrance to the wasteway, are added to the depth at the outfall. These heads are computed in the same manner as in the first and second methods.

The quantities discharged and the corresponding heights in the reservoir by the three methods are plotted on the diagram, Plate LI, and curves drawn through the several determined points.

The quantity of water discharged by the five lines of 24-inch sluice pipes shown in elevation and plan in Plate LI, computed by the formula deduced from Darcy's experiments on the flow through old cast-iron pipes, given in Paper No. 37, in the *Transactions* of the Society for 1872. The head due the initial velocity is computed by the usual formula, using 0.82 as the co-efficient of contraction. The length of the pipes by the original plan is about 100 feet, and the effective head, when the water in the reservoir is 7 feet above the bottom of the wasteway and both pipes and wasteway are discharging to their full capacity, is taken at 70 feet. With these data, the discharge, of the five pipes, is found to be 543 cubic feet per second.

List of Plates.

Plate	XXXVI.	Highest Water at Lewiston, River to extreme right.
"	XXXVII.	Bridge at Lewiston (Lewiston Division of Pennsylvania Railroad). Taken at high water after three spans had fallen.
"	XXXVIII.	Bridge at Lewiston (Lewiston Division of Pennsylvania Railroad), showing wreck after the subsidence of the water.
"	XXXIX.	Buttermilk Falls Trestle, in Conemaugh Valley.
"	XL.	Wreck of the Day Express at Conemaugh.
"	XLI.	General view of the broken Dam, looking northeast diagonally across Dam.
"	XLII.	View of the break in the Dam looking East.
"	XLIII.	View of the break in the Dam looking West.
"	XLIV.	Distant view of broken Dam looking South, and showing stone left on the sides of the valley by the flood.
"	XLV.	Remnants of Gate Chamber in Dam.
"	XLVI.	View taken from a point in the Wasteway, showing bridge and fish screens.
"	XLVII.	Map of Water Shed of South Fork or Western Reservoir.
"	XLVIII.	Dam and Sluices for Reservoirs.

PLATE XLIX. Map showing rainfall within 50 miles of the South Fork Reservoir.
" L. Plan and Profile of the Broken Dam and Wasteway.
" LI. Diagram of computed discharges of water through the Wasteway, etc.
" LII. Diagram of computed discharges of water flowing into the South Park Reservoir at different times during the storm of May 30th and 31st, 1889.

DISCUSSION.

P. F. BRENDLINGER, M. Am. Soc. C. E.—Mr. President, I would like to discuss the report, and make a few remarks about the plans submitted by the committee. I took some levels and measurements at the dam about a year ago and I find quite a discrepancy between my measurements and those given here by the committee. I presume the committee made their own measurements, or employed competent men to do it.

If I mistake not, Mr. Park in his report said, when he got down to the dam there were about 7 feet of water in the spillway and the water then was not running over the dam. Let us stop right here and take up the plate showing the "longitudinal section through center line of dam" and "top view of dam." I am extremely sorry that the crest of the dam is not shown throughout, or, in other words, that the committee has not deemed the matter of sufficient importance or wise, to ascertain or locate the crest line of the dam as it existed before the flood or destruction of the dam. To my mind this is an extremely important link to establish, nor do I think it such a difficult matter to locate, and prove that the crest was no higher, while it may have been lower.

I took very careful levels and measurements about a year after the destruction of the dam, and I find the levels differ from those shown here in the plate about $\frac{4}{10}$ of a foot per hundred, uniformly, in other words, I make the heights from the top of the spillway to the crest of the dam $\frac{4}{10}$ of a foot less than the committee—in all other respects my measurements agree with those submitted by the committee. As my observations were made almost a year after the committee made theirs, the difference in levels may be caused by rains washing the crest of the dam away to a certain extent. Or different points on the top of the sill in the spillway may have been used as the proper place for the elevation of the same. I find there is a difference of about 18 inches between the heights of the bridge at the ends. Whether it is in the bridge or sill, or partly in both, I do not know. I know the height of

the bridge varies. I took the height of the top of sill at a point on the dam side 26 feet from the dam end of the bridge. It is not likely that the committee's elevation of top of sill in spillway was taken at this identical spot, hence the difference of four-tenths may be accounted for in this way. I will therefore discard my levels for the present and present a "longitudinal section through center line of dam," made by myself from the levels and measurements shown on the plan above mentioned (see Plate LIII). This is in fact a reproduction of the committee's plan. I have added to it the "Missing Link Projected" in a heavy dotted line—from point "*A*" to "*B*." I find Station 9 + 50 to have an elevation of 1610.87, and Station 8 + 50 to have an elevation of 1610.07, there is, therefore, a fall or grade of minus eight-tenths of a foot in 100 feet, and at Station 9 + 100 this same grade makes the elevation 1610.47, which is correct. Producing this grade, we have an elevation at Station 8 of 1609.67 and at 7 + 75, the edge of the break, 1609.47 which is just one-tenth of a foot higher than the elevation of the ground as given, but as the rains may have washed the ground slightly we may therefore consider the grade on the "right side" of the crest of the dam as established at — 0.8 per 100 feet from Station 9 + 50. On the left side, unfortunately, we have but a short part of the dam left of a uniform grade, but it is sufficint to determine the grade. The difference between Stations 3 and 3 + 50 is six-tenths of a foot or at the rate of 1.2 feet per 100. Continuing the two grades, the — 1.2 on the left side and the — 0.8 on the right side, the point of intersection is found at Station 5 + 78 at an elevation of 1607.90 or 4.5 feet above the spillway.

The point or points of change from a down grade to a level or rising grade can only occur somewhere between the points *AF* and *BF*, hence I will give the position of the center at *F*, all the benefit in height I can, by fixing the point of curvature at *B*, and projecting a curve whose tangential distances are *BF* and its equal *FK*.

The curve or change may have commenced nearer *F* than *B* or *K*, which would have reduced the height of the dam, but it is impossible to have commenced either between *BE* or *AS*, as the levels plainly show. It is quite evident that the curve or missing link could not have been reversed, as that would not only have been unsightly to the members of the South Fork Fishing Club, but the road would have been hard to use, and besides the water would not have gone over it. It is also highly improbable that *B* was the lowest point and the grade changed to a rising grade from there to *A*, for that would have been noticed by everybody, if not while walking on the road, then from a side view. I regard it as exceedingly strange that there was or is no map of the South Fork Fishing Club's property showing a longitudinal section of this dam before it was destroyed. This club was composed of the best families of Pittsburgh, mostly men of extensive wealth and

business experience, who do nothing by halves. They had a civil engineer in their employ whose report to the committee has highly pleased and gratified me and no doubt all the members, and I must say it occurs to me as being very singular that there should be no such section as above mentioned in existence, and I am perfectly satisfied that the dam was not any higher than the "Missing Link Projected" shows, but may have been lower. I will now give a table of actual elevations as taken, and those measure on the map:

Station.	Elevation.	Ht. above Spillway.	
1.....	1610.44	7.04 feet.	
1 + 36 (Ditch).....	1606.84	3.44 "	
1 + 50.....	1610.04	6.64 "	
2.....	1610.84	7.44 "	
2 + 50.....	1611.14	7.14 "	
3.....	1611.24	7.84 "	
3 + 50.....	1610.64	7.24 "	
4.....	1610.00	6.60 "	Projected Missing Link.
4 + 50.....	1609.50	6.20 "	
5.....	1609.10	5.70 "	
5 + 50.....	1608.80	5.40 "	
6.....	1608.70	5.30 "	
6 + 50.....	1608.80	5.40 "	
7.....	1608.90	5.50 "	
7 + 50.....	1609.20	5.80 "	
7 + 75.....	1609 37	5.97 "	
8.....	———	——	
8 + 50.....	1610.07	6.57 "	
9.....	1610.47	7.07 "	
9 + 50.....	1610.87	7.47 "	
10.....	1611 87	8.47 "	

It is a great pity that the elevation of Station 8 was not taken or put on the plat for it would assist very materially in properly determining the height of the dam. Please observe that the lowest point on the "Missing Link Projected" is at Station 6, and is 5.3 feet above the spillway, and is only 0.67 feet, or 8 inches lower than the edge of the break at *B*. I do not believe any one will, for a moment, doubt that these two opposing down grades towards a common intersection point were connected with an easy inverted vertical curve whose lowest elevation was at least 8 inches below *B*. Various parties have told me the water was deepest in the middle, and parties who went across the dam when the water commenced going over, found the water nearly to the top of their gum-boots in the middle, and only in the middle.

Coming back now to the first part of my remarks, viz.: that when Mr. Park, the engineer for the South Fork Fishing Club, came to the dam he found about 7 feet of water in the spillway, and the water then was not running over the dam. There is a big mistake here somewhere in Mr. Park's statement or in my understanding, or in the committee's levels and my deduced levels—for if there had been 7 feet of water in the spillway there would have been water over the dam to the extent of 1.03 feet at *B*, and 1.7 feet at Station 6.

The depth of the ditch seems to me to have been erroneously taken. The elevation of the bottom is given as 1606.84 or 3.44 feet above the spillway—this makes a depth of 3.2 feet in red shale rock, which seems to me to be impossible to excavate in such a short time, besides, this is 2 feet lower than my lowest projected elevation of the dam and such a quantity of water would have gone through this ditch as to tear up the ground below quite lively. I did not see any evidences of this and in fact would not have observed any ditch or depression if I had not read of it and consequently looked for it, I found a very slight depression below the surrounding general level.

From the report of the committee I understand they attribute the destruction of the dam to the inadequate spillway at *G H*, a point about 175 feet below the bridge, crossing the spillway. I find, from the plat presented by the committee, this, its narrowest cross-section, to have a width of 64 feet at a 4-foot stage of water. I do not know how far the committee went into the examination of the obstruction caused by the bridge and the trestles with the fish-screens under it, but for the information of the members, I present an elevation of the bridge with its barnacles attached as I saw it. As I said before, there is a difference of 18 inches or more between the ends in height of the bridge above the sill, but whether the sill or bridge is level I do not know. The average height from the top of sill to the bottom of the floor is 10 feet, so I drew my bridge parallel with the sill for convenience. All parts and spans showing figured dimensions are plotted to scale, the rest are drawn from a sketch made on the ground. There are, or were a year ago, still three rod screens in position, fastened to the posts, the screens are composed of ½-inch round bars passed through and held in place by top and bottom pieces of 2½ inches by ½-inch iron fastened into two vertical end pieces of the same size. The rods are about 1¼ inches center to center, leaving ¾-inch space between them, this reduces the space, to the height of the bars alone, 40 per cent.

We have at this point a length of sill of 99 feet — reduce this by fourteen posts 6 inches wide and one 8 inches = 7 feet 8 inches or 91 feet 4 inches in all, and 40 per cent. = 36 feet 6 inches, we have a balance of 91 feet 4 inches of this 36 feet 6 inches and leaves 54 feet 10 inches. There is an additional screen which I show at the right side—it is composed of wire ⅜-inch mesh, 3 feet 7 inches high, fastened to a piece of timber 8 × 8 inches, which slides up and down as the water rises and falls by means of an eye at the end, on a rod fastened to the end-post. This piece of timber is almost submerged by its own weight, and with the wire screen attached I doubt whether there is much of it above the surface of the water. The wire screen alone takes up about 25 or 30 per cent. of the area, while the solid timber takes up 8 inches in depth out of 3 feet 7 inches, or 20 per cent. of the total, making a reduction of the available area of 40 to 50 per cent., or reducing the width from 99 to about

Reservoir South Fork Dam
407 Acres
Area of Water Shed of South Fork or Western Reservoir
48.6 sq. miles.
1 mile to Wilmore
½ mile to Wilmore
Cambria County
Bedford County
Crest of the Alleghany Mountains

DAM AND SLUICE for RESERVOIRS.

BY

Wm E. Morris, Civil Engineer.

1839

SCALE 16 FT TO AN INCH

PLATE XLVIII
TRANS. AM. SOC. CIV. ENG'RS.
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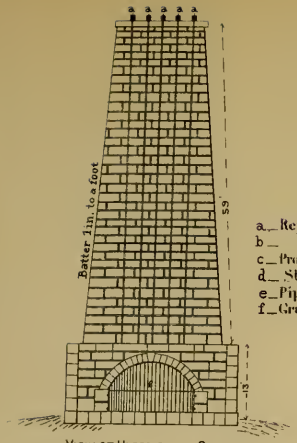
REPORT ON
SOUTH FORK DAM.

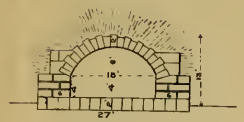
"Copy of a Plan on file in the Department of Internal Affairs of Pennsylvania."

—Reference—

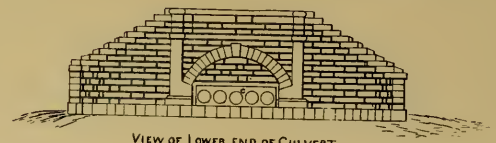
a_ Represents valve rods.
b_ " wall to support pipes.
c_ Protection wall.
d_ Stop cocks.
e_ Pipes.
f_ Grate.



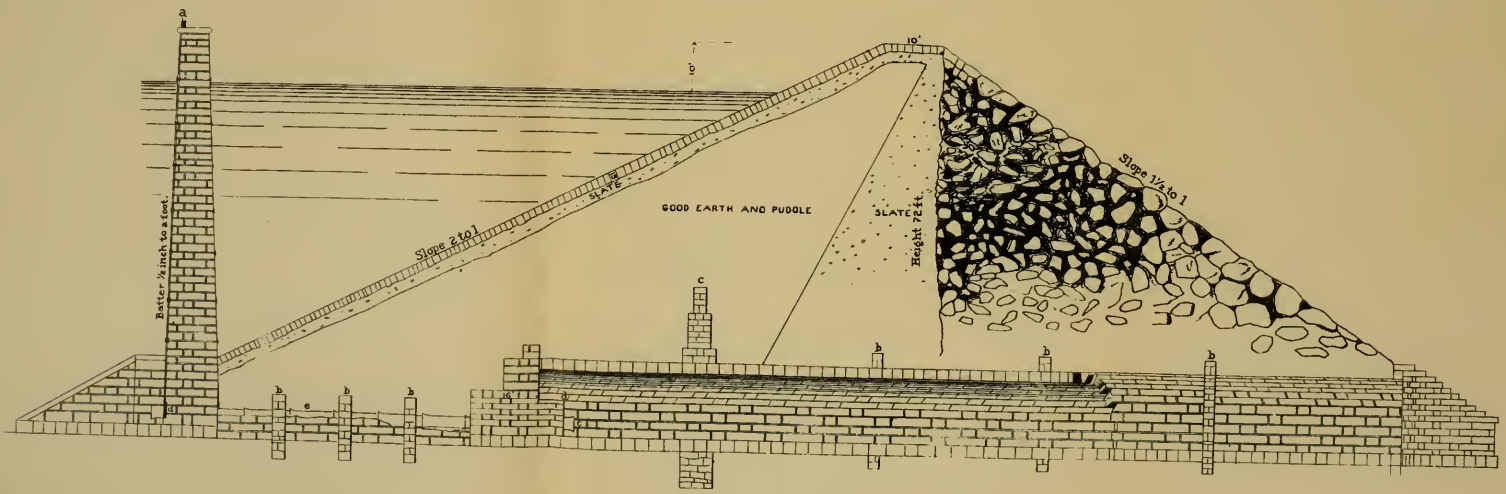
VIEW OF UPPER END OF CULVERT



SECTION THROUGH CENTRE



VIEW OF LOWER END OF CULVERT



MAP SHOWING
RAINFALL WITHIN 50 MILES OF CONEMAUGH LAKE PA.
ON MAY 30 31 1889

Note Of this Rainfall 20 per ct Fell on the 31st

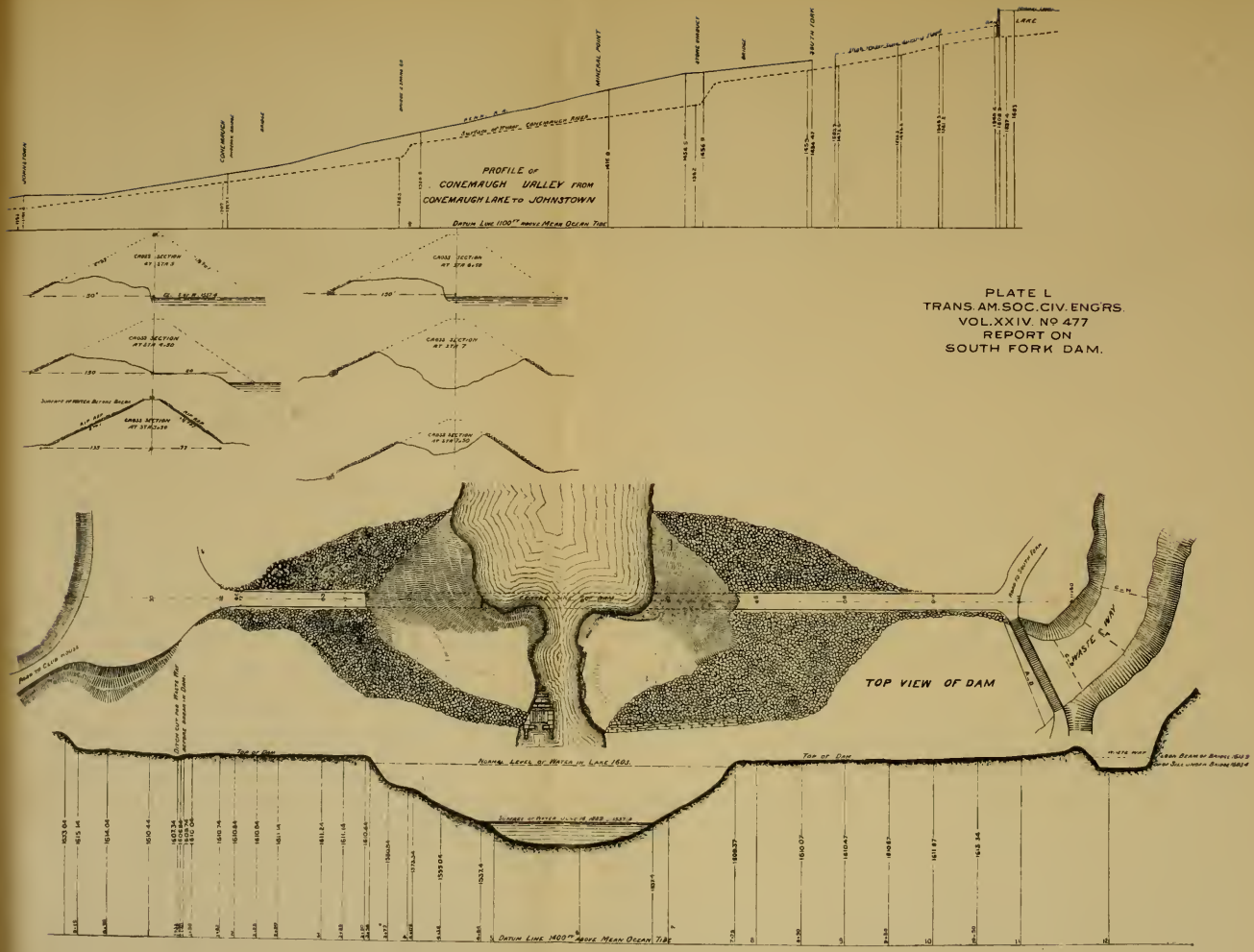


PLATE L
TRANS. AM. SOC. CIV. ENG'RS.
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REPORT ON
SOUTH FORK DAM.

PLATE LI
TRANS. AM. SOC. CIV. ENG'RS.
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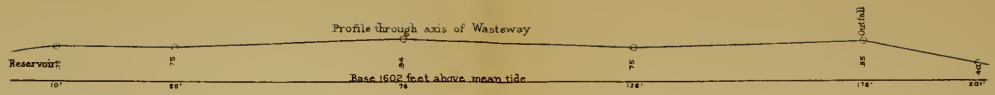
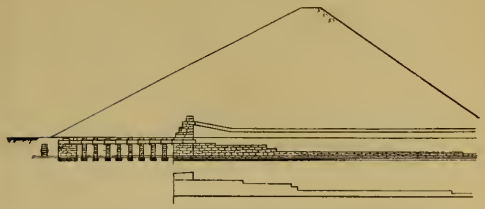
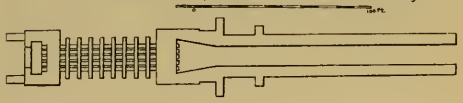
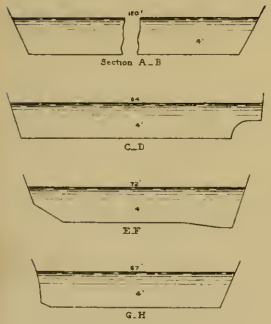


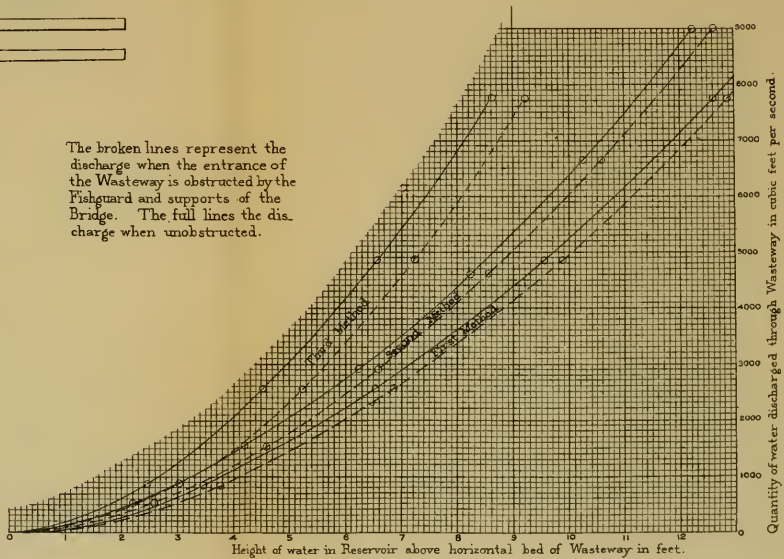


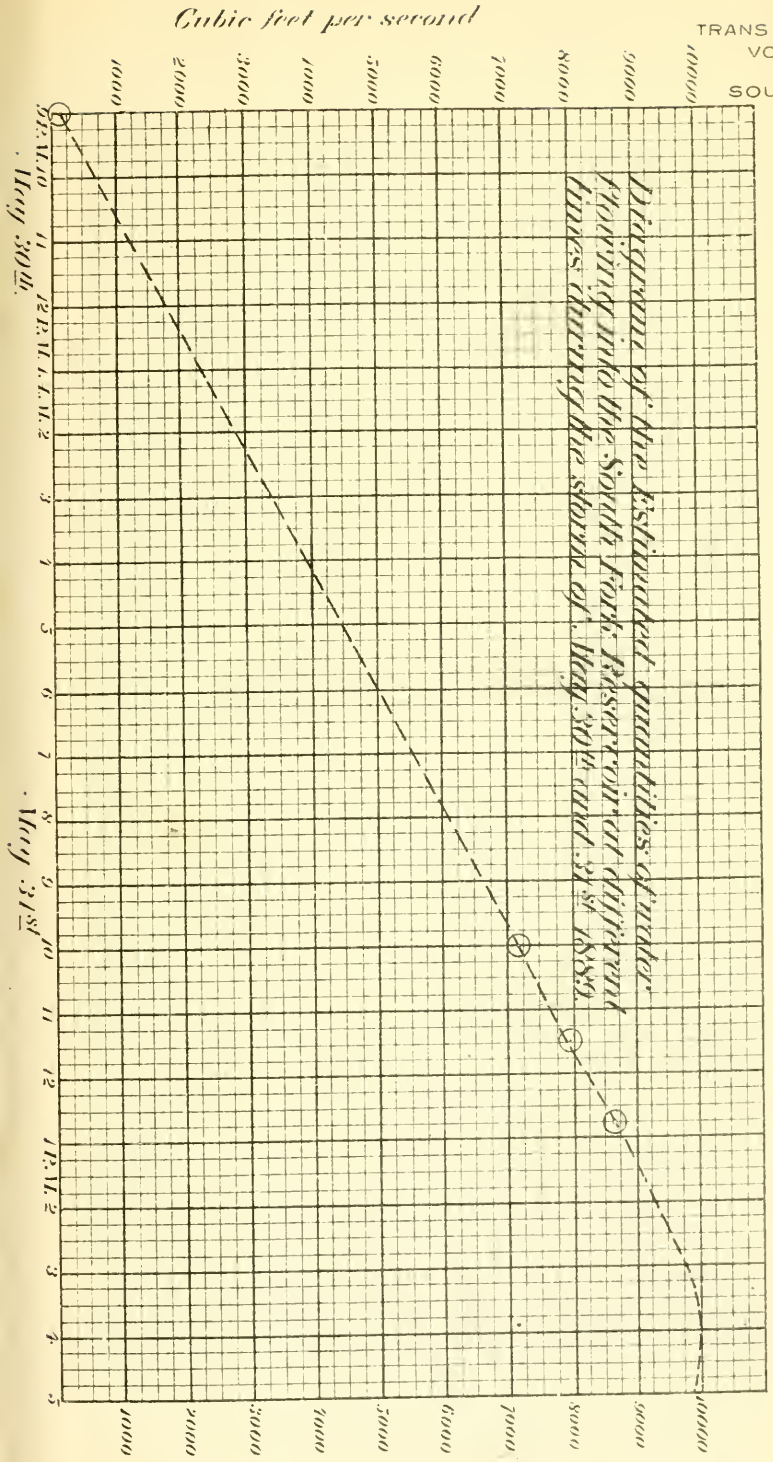
Sketch of Masonry of Western Reservoir previous to 1851.
from Volume 4 of Maps and Plans of Public Works of Pennsylvania.





The broken lines represent the discharge when the entrance of the Wasteway is obstructed by the Fishguard and supports of the Bridge. The full lines the discharge when unobstructed.




Cubic feet per second
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
May 30th.
May 31st.
12 M.
1 P.M.
2
3
4
5
6
7
8
9
10
11
12 M.
1 A.M.
2
3
4
5
6
7
8
9
10
11
12 M.
1 P.M.
2
3
4
5
Diagram of the estimated quantities of water
flowing into the South Fork, at different
times during the storm of May 30th and 31st 1889.

50 feet, which is about 14 feet less than at the narrowest unobstructed cross-section *G H.* I do not understand why the committee did not give a plan showing this bridge with its obstructions. I cannot help differing from the views of the committee that the cross-section *G H* was the controlling point of the spillway, but say that the spillway at the bridge, obstructed by the bridge with its trestles and screens attached, passed less water than at the cross-section *G H.*

I understand from the report of the committee that the original plans and specifications called for a spillway of 150 feet, and the crest of the dam was to be 10 feet above the top of the spillway, Also that Mr. William E. Morris, civil engineer, who designed the original dam, calculated that the greatest rain-fall, of which he could find a record, would produce, from a rush of waters from the entire water-shed, a height of 7 feet above the spillway, and thus 10 feet of crest above spillway would be ample. The question in my mind is now, supposing this spillway had been constructed of a width of 150 feet and reduced by a bridge, trestles and screens from 40 to 50 per cent., would this reduced area have caused the dam to overflow and thus destroy the dam? My answer to this is the same as to the destruction of the dam with the 99 feet spillway, viz.: if the crest of the dam had been 10 feet above the spillway, the water would have crushed, and swept the wooden bridge out of the spillway before it would have gone over the dam and thus saved the dam. The dam, as reconstructed in 1880, and destroyed in 1889, had, as far as we know, not quite 6 feet of embankment above the spillway, without doubt only 5.3 feet, and the water went over the embankment before the bridge and obstructions could be torn out. It is very evident to my mind that had there been a few feet more in height to the crest of the dam, the water would not have gone over the dam, as no doubt this seemed to be Mr. Park's idea, as he turned up a little ridge of earth on the embankment to keep the water from going over the dam, the water then, as I understand it, was not rising very fast, but had almost reached its maximum height, besides this, every foot in height added to the crest of the dam would tend to spread the water over a large flat territory, in other words, 1 foot at the top frequently backs up a larger quantity of water than 10 feet at the middle of the dam, besides, no doubt if the dam had been several feet higher the water would soon have swept away the bridge and obstructions and the dam would have been saved. There is no question in my mind that the spillway was too narrow or small to speedily discharge the waters from the dam in a great rain-fall, but to my mind the greatest danger lay in the low embankment, only 5.3 feet, or at most 5.97 feet above the spillway and the obstructions in the spillway.

As to the material in the dam, I do not propose to repeat what I have already said at previous meetings of the Society how that dam was built; I only wish to say one word, that is, there is certainly a mistake some-

where, either in my recollection or in the report of the engineer that was read this morning, viz.: that the material was rolled when the dam was rebuilt in 1880. As I saw it, it was dumped in place out of carts, the same as material is put in railroad embankments. Whether it was rolled subsequently to that, I do not know.

In regard to the little embankment that was thrown up on the crest of the dam, I found very little evidence a year afterwards that there had been more than probably six inches altogether of a ridge thrown up.

Mr. Wilkins.—I think Mr. Brendlinger has misunderstood Mr. Park's statement in regard to the 7 feet, etc.; it was above the dam, nearly a mile, and I think very likely the difference of four-tenths would be in the hydraulic grade between the cottages and the dam.

Robert Moore, M. Am. Soc. C. E.—I presume that the basis of the levels was the same in both cases, was it not?

Mr. Brendlinger.—Yes; they took the top of the sill to start; I started on top of the sill with my levels, so that I would have a comparison from the same basis.

F. Collingwood, M. Am. Soc. C. E.—I did not propose to take part in this discussion. I took some very careful levels on the dam, checking them in both directions. I made the elevations of the dam, practically the same as the committee made them. I am credibly informed that there were frequent repairs of the road on top of the dam, and all theorizing as to the "missing link" is therefore based on an uncertainty.

There is one other point, which I do not pretend to say is or is not the case. I was told by the Superintendent of the South Fork Fishing Club that the floating fish-screen and the end triangular screen were not in place at the height of the freshet, and that a portion of the gratings was not there. They probably were as shown in Mr. Brendlinger's sketches. The three screens in place were 18 inches high, made of ½-inch rods, with 9 rods to the foot. We ought to rely on the committee's statements rather than on anything obtained subsequently, because when the committee was there all the flood-marks were visible, and both Mr. Brendlinger and myself were there long after the occurrence and the flood-marks were gone. I am very clear from careful measurements I have taken that, with all those fish-screens in at the bottom, the section of the wasteway at the bridge was considerably greater than the smallest section below the bridge. If I remember, the report states that the section below was the controlling point. I append a copy of a photograph of the dam which was taken from the level of the crest before this accident occurred, and it is so nearly level that you cannot see any depression. To my mind, after a very careful examination of the whole surface of the crest, I decided that there could not have been any very great depression in the center; not only from what I saw, but what was told me. One intelligent man who was engaged at the dam, at the

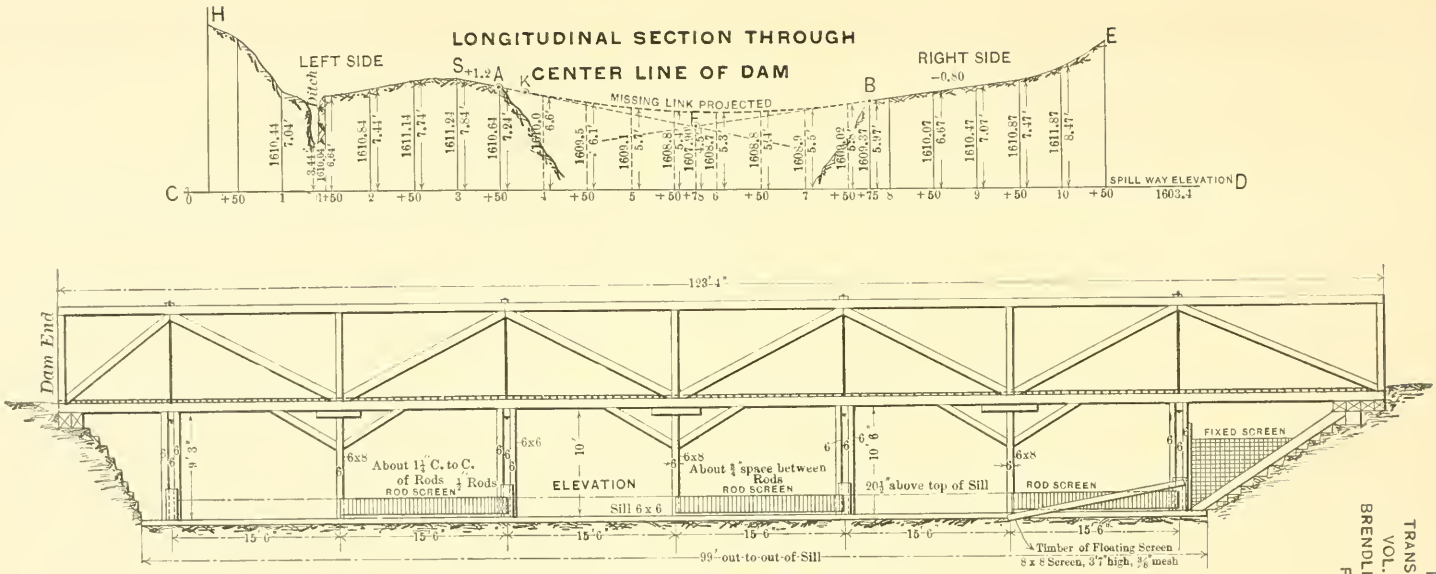
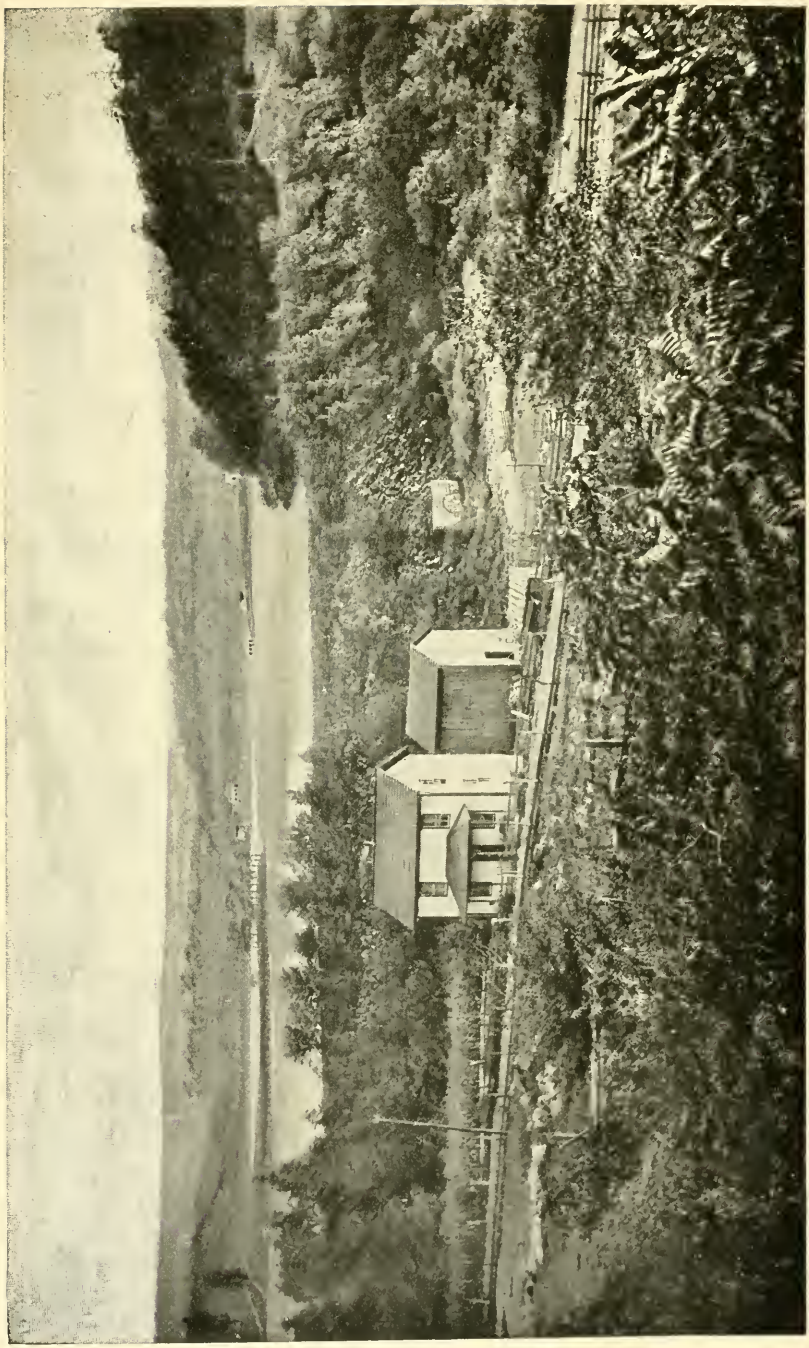


PLATE LIII.
TRANS. AM. SOC. C. E.
VOL. XXIV, No. 477.
BRENDLINGER ON SOUTH FORK DAM.

PLATE LIIIA.
TRANS. AM. SOC. C. E.
VOL. XXIV, No. 477.
COLLINGWOOD ON SOUTH
FORK DAM.



time of the disaster, said that there was a very general crossing over; that they were crossing to and fro through this water for a long time after the water began to go over, wading through the water for a length of some 300 feet. There could not have been any very great depression, as it did not come over their boots. A careful reading of Mr. Park's report fully bears out the committee's conclusions. The statement is clear that the water flowed over at numerous points over a length of 300 feet before it became a sheet, and that it began flowing through the new trench first.

Henry T. Goldmark, M. Am. Soc. C. E.—I have not been at the dam since the accident occurred, and I think perhaps more people have seen the place since than before the disaster. I spent two summers in Johnstown, in 1884 and 1885, and happened to go to this place some half dozen times, and I am very sure that there was no marked depression in the roadway across the dam. We climbed around there a good deal. We were quite a little impressed by the way the waste-weir was obstructed, but that there was any marked depression in the dam never struck us at all.

Mr. Brendlinger.—If there was a uniform slope, as I have projected it, then a curve would be as nearly correct as could be made. I plotted all these levels out, and I got a curve plotted very nicely. Because an embankment looks level to the eye does not go to say that it is level when you put the level on it. There is a regular drop on both sides of the gap toward the center. It is natural that the dam should be lower at the center than at these points, for the simple reason that this new material was put in in 1880, and, of course, the greatest settlement will be where the deepest part of your embankment is. Of course, you can keep that raised. Why it was not done I do not know.

Mr. Collingwood.—In answer to that I will state another point which was stated to me. I had it from two or three persons that the little furrow that was thrown up by a plow on top of the dam, the water did not begin going over at all until it went over at many places at the same time. That furrow was very hard to plow; the elevation, as we saw it, was some 4 inches only, but it had been worn down by rains. The water did not go over at the center first, but at many places all along its length. If that is so there could not have been any great difference in level. Taking all fair evidence, I could not find any indication of any very great depression.

As to the credibility of reports a year after an occurrence, I was told by a carpenter, who was employed at the cottages, that he saw the water about 20 inches deep on a sidewalk there. Levels taken from this point to the high water mark at the dam showed a fall of over two feet in about a mile. This, in a lake of such dimensions, is incredible.

As proof beyond gainsaying of the magnitude of the flood, all the bath houses and a handsome boat house were utterly wrecked, and a

dam near the mouth of one of the streams forming the lake went out with such a flood that the proprietor could not tell when it happened, it was completely drowned out. It had stood there for sixty years. The proprietor also stated that a pail, which was empty the night betore, had 6½ inches of water collected in it from the rain during the night. This was at a point about two miles above the dam.

James B. Francis, Past President Am. Soc. C. E.—As to the depression, the dam had been lowered about 2 feet to make the roadway, near the ends there were ascents to the level of the top of the dam. On each side of the breach there were slight depressions in the roadway undoubtedly due to corresponding settlements due to the breach. These several points being connected, would give a line substantially a curve, which continued across the breach, would indicate as suggested, a considerable depression at the middle of the breach, but the form of the curve depends on the depressions on the sides of the breach which did not exist until the breach was made, and the curve is consequently no proof of any original depression, although it appears from other sources that there was some.

Mr. Collingwood.—You estimate there was a depression of 2 feet below the original height?

Mr. Francis.—Yes. The top of the dam was originally 10 feet wide, which was too narrow for a roadway, and the dam was cut down 2 feet.

As to this matter of the fish guard obstructing the flow of water in the wasteway, it did so to a considerable extent, when the depth of water flowing in the wasteway was smaller. In high stages of the water, the controlling point was in the wasteway about 176 feet below the fish guard; at the fish guard it was over 100 feet wide. While at 176 feet from the fish guard it was only 70 feet wide. The bed of the wasteway for the first 176 feet was about level. At the point where it was about 70 feet wide it commenced to fall, and this was taken as the controlling point. When the fish guard was in action, there were floats above the fixed part, which rose and fell with the water. One of these I saw after the flood. During the flood the attempt was made to pull away the fish guard, but with not much success.

Mr. Brendlinger.—Did you make a plan or cross-section at the bridge? The elevation of the bridge with the screens?

Mr. Francis.—Yes; I measured that myself and it is taken into account in the calculations.

Mr. Brendlinger.—In regard to the screens, I may say that there were three screens in position and one or two below the bridge, lying there. It looked to me as though they were forced out of place by the water; one end of the wire screens is still there.

As to that waste weir, I made it 190 feet to the narrowest point of the spillway from the upper end of the bridge, 55 feet wide at the base and on the right-hand side a slope of 2 feet, then 10 feet from there to

the rock, that made 65 feet wide when the water might have had an elevation of 4 feet. On the other side there was a one to one slope, which of course gave a wider slope.

The top of the dam I made 10 feet wide on the north side; I suppose it is 15 feet wide on the south side.

Mr. Francis.—As the slope below 176 feet from the fish guard was amply sufficient to maintain the velocity, we did not consider that any small inequalities in the section would affect the flow from the lake.

Mr. Brendlinger.—That was below; 190 feet from the upper end of the bridge.

Mr. Francis.—The point I speak of is 176 feet, not 190 feet down stream and that is where it began to pitch off.

Mr. Brendlinger.—I made it 190, you make it 176.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

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(Vol. XXIV.—June, 1891.)

CHARACTERISTICS OF THE RAVINE DU SUD IN THE ISLAND OF HAYTI, AND PLAN FOR AVERTING ITS OVERFLOW.

By J. FOSTER CROWELL, M. Am. Soc. C. E.

WITH DISCUSSION.

The writer recently had occasion to make an extended examination and study of the Ravine du Sud, having been retained by the Haytian Government as Consulting Engineer to devise means of relief for the City of Aux Cayes against further occurrences of the disastrous floods of the past.

The word ravine is here to be taken in its French significance, implying a raging torrent and not merely as a term of topographical configuration. This ravine is a typical tropic "torrentiele," with strongly marked characteristics, and furnishes an interesting object-lesson in the phenomena of sporadic rainfall, for the investigation of which there are few opportunities.

The floods with which we are generally more familiar in our own country are either periodic, such as are augmented by melting snows, or caused by ice gorges, or due to long-continued rains; or else they are accidental, like the Johnstown flood, or the freshets are in streams

that have been modified by artificial dams and other obstructions or encroachments. For the first class, nature has generally provided adequate channels, and the engineer in dealing with them has only to avoid interference. The second class is unlooked for, as a matter of course; consequently, when great floods do occur, they receive only momentary attention, and in degree proportioned to the calamity.

The tropic floods, however, are neither periodic nor accidental. They occur sometimes with great frequency, and again at intervals of years. While always to be looked for at certain seasons of the year, they cannot be foretold, and they come with surprising swiftness and irresistible power. It must not be understood, however, that this describes a condition that can be correctly styled "tropical." In different localities in the same latitude, with apparently similar prevalent conditions, there will sometimes be found wide variations both in rainfall and in temperature, that to the ordinary observer are inexplicable. Of course there are fixed laws, unalterable in operation, but their system is too complex for him who runs to read.

Among the most interesting indices of the vast variants in the matter of rainfall are the so-called torrential streams, which are, in fact, not streams at all, but immense dry courses provided by nature for exigencies that may occur, only at long intervals of years, or repeatedly in some one season; such channels are not peculiar to the tropics, but are found in any mountain region, where there are great fluctuations in the rainfall. The islands of Hayti and San Domingo contain some marked specimens of these "torrentieles," and furnishes a clear exposition of their function.

An examination of the map of Hayti, shows that nearly all the rivers of continual flowage are on the northern sides of the several mountain ranges. The western end of the island is almost entirely mountainous, with a comparatively very small area of plain, so that it may be said to consist of two lofty ranges running east and west, separated by the Gulf of Gonaives. For their height, these mountains are very narrow at the base. Their southern slopes are short and steep and receive little rain, even though the precipitation directly upon and along the southern coast line may at the same time be very great. This may be in part attributed to the fact, that the temperature on the southern slopes is normally higher than that on the northern, which are longer and not so exposed to the sun-action. When the south winds blow, the currents of warm,

moisture-laden air from the Carribean Sea are deflected upward where they strike the heated mountain flanks, and drop little of their load there; but on the cooler northern slope, precipitation occurs very much more frequently, and rivers of considerable size are kept supplied. When the colder winds blow from the north, there is obviously less moisture and consequently less rain. It is quite clear, then, the above being granted, that to produce heavy rainfall on the southern slopes there would have to be:

a. Lowering of the temperature of the mountain surface by unusually cold air currents, aided by the interruption of the sun's rays because of continual cloudy skies.

b. Sudden change of winds to warm water-bearers from the Carribean.

c. Violent electrical disturbances to cause sudden precipitation.

Now, any of these three causes is likely to occur frequently in any season, but their coincidences may be extremely rare. Any one of the three would produce rain in greater or less quantity, but it is only when all act together, probably, that the terrific floods occur which bring the torrentieles into play. This culmination, too, would likely result in setting up for the time being new conditions of temperature, and so the result would not be momentary, like the "cloud-bursts" of the temperate regions, but, when produced, would continue with gradually decreasing energy until the normal was once more restored. And this in fact is what follows when a tropic flood "lets go."

On the southern coast of Hayti is the City of Aux Cayes, the second town and port in importance. The Ravine due Sud is the course of a torrential stream rising in the La Hotte range, and discharging into the Bay of Cayes. A number of branches, none of them inconsiderable in capacity, unite near Camp Perin, about 30 kilometres from the coast, and flow as one river to the sea. Their fall above the junction is very steep, and the waters attain immense velocity. During most of the year the quantity of water is very small, but in the rainy season the flow reaches large proportions. Infrequently, there are enormous freshets occurring irregularly, at intervals of years, and resulting from the culmination of the causes which have already been treated of. The quantity of water passing at such times is incalculable, excepting by carefully measuring the probable maximum, as witnessed by those parts of the ravine which bear clear evidence of having been filled to the brim, but

of never having been overflowed. There is no data of rainfall at hand and no means of securing a record. It must be quite evident, however, that under the conditions cited, no record would be of scientific value that did not cover the flood times and specialize the cloud-bursts in all the tributary territory. Equally obviously, the flood to be guarded against is the extreme condition, and the unknown quantity to be computed is the aggregation of waters in the lower ravine. The method of computation as accomplished in this case will be given hereafter.

Immediately below the confluence at Camp Perin and extending down for several kilometres, the ravine bed is at places nearly 300 metres (or about 1 000 feet in width, varying from that to 150 metres); the banks there are formed chiefly of gravel which has been cut out vertically by the torrent and carried down stream; the coarser material, nearly to Les Cayes, the finer sand and clay, still further to the sea. The bed is covered with large rounded stones from 3 to 6 decimetres (1 to 2 feet) in diameter, that have been rolled down from the mountains by the force of the current. The general level of the banks above the bed is usually about 2½ metres, though occasionally cliffs 10 metres or more in height are met. The stream cuts the width it needs, from time to time, without apparently exceeding the usual flood level.

In the dry season, the flow of water in the lower reaches of the ravine is much less than here at Camp Perin; which somewhat paradoxical condition, is due partly to excessive evaporation, but chiefly to percolation into the gravelly formation; this element is, however, too small in effect to be considered in time of freshets. This compartment of the ravine, from which the sand and gravel have been carried to the sea to make room for the larger rolling stones from the mountains, extends as far down as Carrefour Fond frede (Plate LIV). Next below that, to the crossing of the Route Drouet, there is a compartment that has been scoured out but not refilled, because the velocity of the torrent, diminishing with distance from the mountains and as the more level country is reached, is no longer sufficient to transport the large stones. Down to this point, the work of the torrent is confined to its own bed; there is so far no trace of any overflowing of the banks, and traditions speak of such only vaguely. Nature has thus provided a means of checking the velocity of the torrent and storing up the waters for slower discharge onward to the sea.

For a short distance below the Route Drouet, the unimpaired banks show clearly that the equilibrium has been reached, and indicate that if a uniform channel had extended thence to the mouth, all the water of any flood would pass off in time, harmlessly. But below Drouet the existing channel, unfortunately, only continues to be of sufficient width as far as the Route Torbeck, distant but 1½ kilometers; here the present bed suddenly contracts, and a short distance beyond, is not sufficiently wide to discharge the most ordinary flood. Two kilometers further down and for a considerable distance below, the sectional area is only one-half of the adequate water way at Drouet. As a natural and inevitable result, the stream at flood has gone over its banks in the vicinity of the town, not only in the narrower parts but also above them, because the accumulating waters were thus held back, and added to the flood quantity. (See Plate LV.)

Although two memorable floods have occurred in recent years, the first of which ruined the stately Quatre Chemin, while the second tore to pieces the newly constructed engineering works which had been planned to control it, the widening of the lower channel has never been attempted, and the conditions are now the same as formerly. The damage has never been repaired, and the entire city lying low upon the beach, is always subject to the liability of another flood as great or greater than the last, which might work untold havoc.

There is another description of damage, less thrilling than destruction by flood, that has been silently but continuously going on, of which the Ravine du Sud is also the agent, and that is the impairment of the harbor. Light freshets bring down sand and mud and deposit them in the harbor; thus a bar has been gradually formed across the mouth of the ravine, which has at length risen above the surface of the ocean, and, augmented by the wave-action, has during the past season completely shut off access by boats to the river mouth, and the lightermen can no longer take their lighters into the smooth water which used to be their refuge in stormy weather. To repair the damage already done to the harbor will be a matter of difficulty and great expense; but a greater damage menaces the wharf and the business front of the city, which will be inevitable with the next great inundation; for unless steps are taken to avert it, the flood will make a new outlet for itself along the line of least resistance, not through the new bar, but parallel to it across the root of the wharf. It is apparent, then, that it is vitally necessary for

the preservation of the harbor, as well as for the security and prosperity of the town and its inhabitants, that the ravine should be given an artificial outlet elsewhere than in the harbor; and, furthermore, the closing up of the present mouth also threatens the health of the city, by cutting off entirely the exit for the drainage that finds its way into the already stagnant waters of the River Renaud. The means of relief which have been recommended are, briefly, to excavate an enlarged channel from the route Drouet to the sea at a point outside of the harbor, and to protect its banks wherever necessary, with adequate revetements of a permanent character. If it were possible to divert the waters of the Ravine du Sud, entirely or in part, and to lead them to the sea through the channels of other rivers, that would obviously be the best disposition of them so far as Aux Cayes is concerned, at least from the flood standpoint, although it would leave the question of public health to be met in some other way. With the possibility of such a diversion in view, careful and extended instrumental examinations of the relations of other streams were made, to ascertain positively whether such a scheme was practicable. The feasibility of erecting a dam, with gates, across the ravine just above Drouet, thus creating a large reservoir for impounding the flood-water and letting it off gradually, had also been taken into consideration; but this idea was abandoned as being both precarious for the present and ineffectual in the future, as well as very costly. To build it would simply be creating a trap for posterity. The plan of diverting the waters seemed more promising, and the hopes of being able to do so were enhanced by the supposed practicability of joining the upper Ravine du Sud with the valleys of the Ravine Seche and the River Torbeck; in fact, tradition pointed to this actually having been done by nature in times past. But the cold logic of facts brought out by the surveys, has demonstrated that this is entirely impossible, for both those valleys are higher than the Ravine du Sud, and are already insufficient for their own discharge. To tap them would be enormously costly, and the only result would be to drain them into La Sud. It is, therefore, an unavoidable conclusion that the present course of these waters must be adhered to, and the works of improvement must be directed toward increasing the width of outlet channel and providing a new mouth.

The problem first to be solved was: "Given the greatest flood that can possibly occur in the ravine, what are the dimensions of the new

channel which is to lead it harmlessly to the sea?" The difficult parts of nearly all problems are the data, and in this case the data had to be constructed. There had been no flood for several years; might not be another for a still longer period; there was no record of rainfall nearer than Port au Prince, and it was not applicable. Even if it could have been accepted as a general guide, to use it would have necessitated measuring superficially various water-sheds contributory to the ravine, covering large areas of steep mountain sides and gulches, practically inaccessible and almost impenetrable. A survey in a balloon might have accomplished it, but available means could not. But nature makes her own records, and in this case had done more than that—she had left her water-meter behind her.

If the reader will glance again at the map, and recur to what has been said about the form of the ravine, he will perceive that above Drouet the bed spreads out like the swell of a bottle's shoulder, while below, it is the narrower neck. Still lower down, the banks are ragged and torn and widened; that is, where the discharge through the neck of the bottle has overfilled a too shallow basin. This neck of the bottle, or this nozzle, if you please, has always heretofore been capacious enough for the moving flood, and if there has been at any time (and, doubtless, such times have been many), more water than could pass through, the excess has quietly stayed in the bottle, which is large enough and to spare. Inferentially this will continue to be so, and the neck of the bottle is the measure of the future flood.

There being, as has been stated, no sufficient data of rainfall or of observed water-marks of the stream at flood, the maximum discharge was arrived at by carefully gauging the capacity of a portion of the ravine at the head of the proposed works, a short distance south of Drouet, about 2½ miles from the sea. The portion selected was 600 feet in length, it was very uniform in cross-section, with vertical banks, level bottom, no deposits of boulders or silt, and no indication of overflow on the banks. Reliable testimony from several sources corroborated the assumption that the banks had never been inundated, even at the time of the greatest, which was also the most recent, flood. While on the other hand the clean-cut banks showed clearly that their level had been very nearly if not quite reached, and this also was confirmed by the testimony of eye-witnesses and by the flood-marks further down the stream. This compartment, therefore, furnishes in itself the most authentic and

comprehensive measure of the maximum discharge. From averages of a number of cross-sections taken in this compartment, a typical section was constructed, for which the wet perimeter and hydraulic mean depth were deduced. The fall of the surface of the hypothetical flood was carefully determined.

These values were then applied to Stevenson's formula, in which the discharge is a function of the hydraulic mean depth and the fall. It may be convenient to state the formula as follows:

$$X = Y\sqrt{A\,F}$$
$$Z = \frac{X \times 5\,280}{60} = 88\,X$$
$$D = S\,Z.$$

In which

$X =$ mean velocity of the whole cross-section in miles per hour.

$Y =$ is a frictional co-efficient which is found to vary from 0.65 for small streams under 2 000 cubic feet per minute, to 0.9 for large rivers, but which is here taken as unity to insure the largest probable maximum.

$Z =$ mean velocity in feet per minute.

$A =$ hydraulic mean depth in feet.

$F =$ fall in feet per mile.

$S =$ area of section in square feet.

$D =$ discharge in cubic feet per minute.

Below the point at which the typical section is applied the fall of the natural surface is at the rate of 26.5 feet per mile for 2 000 meters, 17 feet per mile for the next 1 000 meters, and 15 feet per mile thence to the sea. Applying the same formula, but giving Y a value of 0.75, we find the respective areas of channel required to pass D. ($D =$ in this case 500 000 cubic feet per minute.)

In order to minimize the velocity of flood in the new channels, the wet perimeters are increased beyond that of the typical cross-section, and to an extent to make the required depth in new channel, approximately 5 feet throughout. This also makes it feasible to construct the greater part of the new channel entirely below the level of the plain, thus securing an important element of safety; but it is contemplated to obtain a large margin of available section by banking the excavated material above the level of the plain, setting the embankments well

back from the edge of channel and planting them with protecting vegetation. In several localities where the flood surface will necessarily be above the plain, and at others where curved alignment is unavoidable, the banks are to be protected with imperishable revetements of beton, encased with a structure of creosoted timber. Several types of the proposed construction, to suit varying conditions, are shown in the accompanying drawings (Plate LVI). The cost of these revetements is very great per unit of length, but their aggregate length being comparatively small, the expense is justified by the close approach to absolute security at the vital points.

The location sheet (Plate LV) shows two alternative plans; the preferable location is the one more remote from the harbor, but its cost is considerably greater. The improvement comprehends also the question of drainage of the town into the new channels, and the filling up of the bed of the stagnant River Renaud.

DISCUSSION.

Mr. Rudolph Hering, M. Am. Soc. C. E.—In order to find the dimensions of a new channel, which was to lead the greatest flood discharge harmlessly to the sea, Mr. Crowell uses Stephenson's formula, which determines the mean velocity of water in a given section by the mean hydraulic depth, the slope and a certain co-efficient given by its author. Having some misgivings regarding the application of the formula for the case in hand, I made some examinations into the result given by it, as compared with those given by others, and also with actual gaugings made in rivers located on the northern slope of the Alps, having irregular beds of gravel and high velocities, and resembling in their physical character the Ravine du Sud, with cross-sections and slopes both smaller and greater than those of the same ravine. It may be interesting to note this information, and to observe that the Stephenson formula and others give discharges largely in excess of what may be expected from actual gaugings of similar streams.

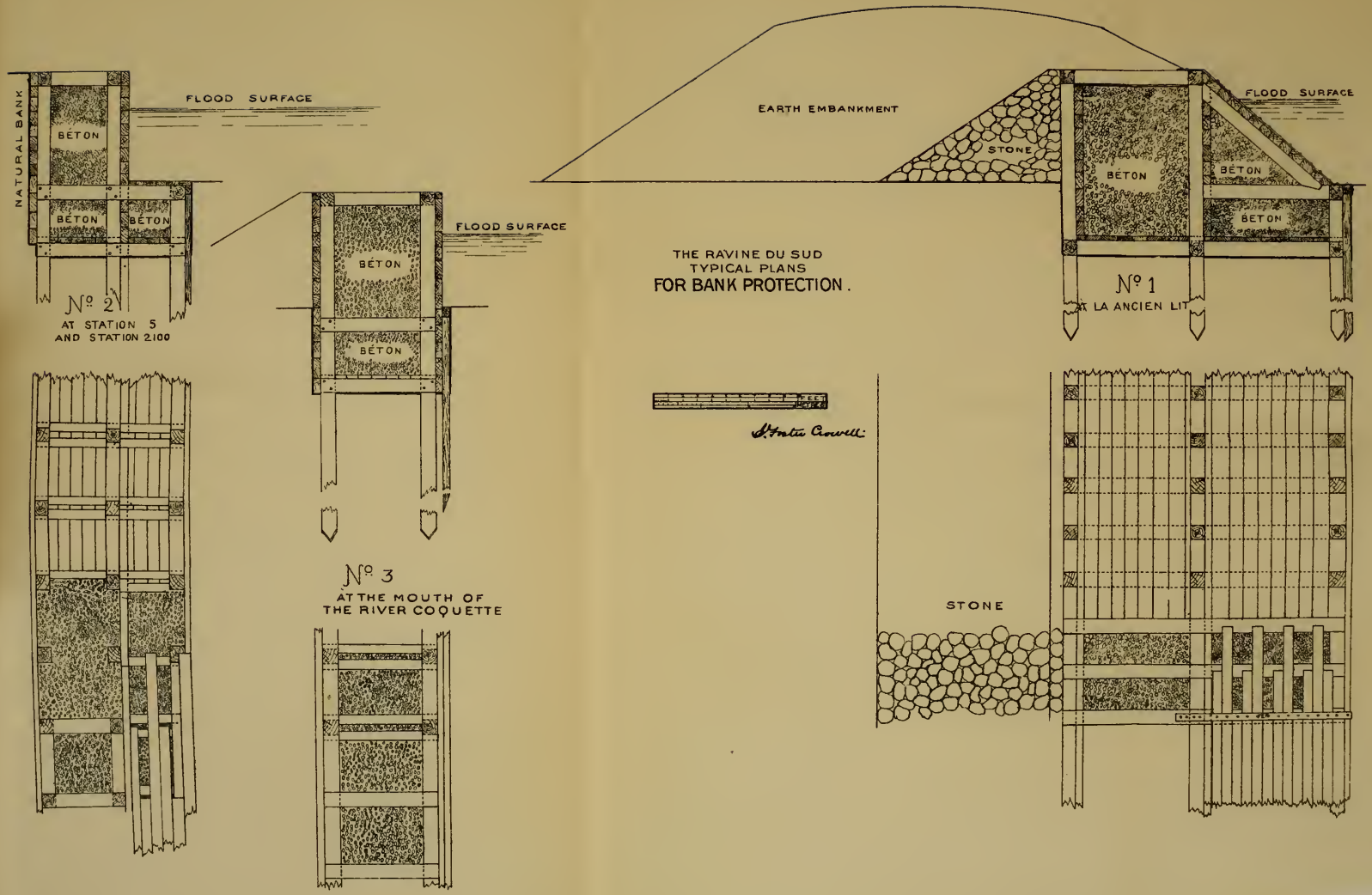
The following are the various formulas and values of co-efficients suggested by engineers for large and rapid rivers, or for more general application, which, therefore, include the same. In these formulas (feet and seconds) R = hydraulic mean depth. S = sine of slope. c = co-efficient. v = mean velocity.

The fundamental formula used by all authors is that of Chezy namely:

$$v = c\sqrt{RS}.$$

GENERAL MAP OF
THE RAVINE DU SUD
ISLAND OF HAYTI

RAVINE DU SUD
LOCATION MAP, SHOWING
PROPOSED (ALTERNATIVE) CHANNELS
RAVINE DU SUD
ANCIEN LIT DE LA RAVINE
ANCIEN COURS MAPPET
ROUTE TORBECK
ROUTE DROUET
CHAUSSEE QUATRE CHEMIN
BARRE ROUGE
PORT ALEXANDRE
ANCRAGE
ANCRAGE


NATURAL BANK
FLOOD SURFACE
BÉTON
BÉTON
BÉTON
No. 2
AT STATION 5
AND STATION 2100
FLOOD SURFACE
BÉTON
BÉTON
No. 3
AT THE MOUTH OF
THE RIVER COQUETTE
EARTH EMBANKMENT
STONE
FLOOD SURFACE
BÉTON
BÉTON
BÉTON
No. 1
AT LA ANCIEN LIT
THE RAVINE DU SUD
TYPICAL PLANS
FOR BANK PROTECTION.
STONE

The values of the co-efficient c, as given by them, are as follows:

First.—Constant values for c:

Young (large rivers) ..... $c = 84.3$
Eytelwein (rivers) ..... $c = 92.2$
Neville (straight and rapid rivers) ..... $c = 93.3$
Beardmore (rivers) ..... $c = 94.2$
D'Aubuisson (rapid velocities) ..... $c = 95.6$
Stephenson (large streams) ..... $c = 96.0$
Taylor, Downing and Leslie (large and rapid rivers) ..... $c = 100.0$

Second.—Variable values for c:

Humphreys and Abbot (simplified) ..... $c = \frac{9.67}{\sqrt[4]{S}}$

Darcy and Bazin (not intended for large rivers) $c = \sqrt{\frac{1}{\alpha + \frac{\beta}{R}}}$

For earth $\alpha = .000085$, and $\beta = .00035$.

Ganguillet and Kutter ..... $c = \dfrac{41.6 + \frac{1.811}{n} + \frac{0.00281}{S}}{1 + \left(41.6 + \frac{0.00281}{S}\right)\frac{n}{\sqrt{R}}}$

Table No. 1 gives the numerical results obtained from the above formulas for the co-efficient c, for the mean velocity v, and for the discharge. The author, Mr. Crowell, has kindly furnished me with the following elements to enable these calculations to be made:

HYDRAULIC ELEMENTS OF THE RAVINE DU SUD.

R (A in Mr. Crowell's paper) = hydraulic mean depth = 5.5 feet.
Sectional area of typical cross-section = 569 square feet.
Wet perimeter of typical cross-section = 103.5 feet.
S = sine of flood slope = .00322.

Mr. Crowell further describes the bed as being smooth and level, clean and covered with small gravel. The sides are nearly vertical and smooth.

TABLE No. 1.

FORMULAS OF —		Co-efficient c.	Mean Velocity v.	Discharge D
Young,	Constant values of c.	84.3	11.21	6378.49
Eytelwein,		92.2	12.26	6975.94
Neville,		93.3	12.41	7061.29
Beardmore,		94.2	12.53	7129.57
D'Aubuisson,		95.6	12.71	7231.99
Stephenson,		96.0	12.77	7266.13
Taylor,		100.0	13.30	7567.70
Stevenson,*		106.6	14.18	8069.90
Humphreys and Abbott,	Variable values of c.	40.61	5.40	3072.60
Darcey and Bazin,		82.03	10.91	6207.79
Ganguillet and Kutter,		56.29	7.49	4261.81

* As modified by Mr. Crowell.

Mr. Crowell's description of the character of the bed being smooth and level, with clean and small gravel, is hardly consistent with the velocity he obtains by Stevenson's formula, namely, 14.18 feet per second. Such a velocity would carry along small gravel in suspension. This description, therefore, I think does not characterize the condition of the ravine during the time of the freshet, but only when the flow is very slight.

I will now give a table (No. 2) and corresponding diagram, which show results of actual gaugings in similar channels, near the foot of the Alps. Fortunately these gaugings give elements both larger and smaller than the case in question. We therefore have much assurance that our interpolations are not far from the truth.

TABLE No. 2.

GAUGING OF RIVERS ON THE NORTHERN SLOPE OF THE ALPS. (See "Flow of Water in Rivers," etc. By E. GANGUILLET and W. R. KUTTER. JOHN WILEY & SONS, 1889.)

DESIGNATION ON DIAGRAM.	NAME.	MEASURED.			COMPUTED.	
		R	*S*	*v*	*c*	*n*
a	Salzach	7.39	1.12	5.79	63.4	.0337
b	Aar, near Thalgut	7.06	1.78	6.77	60.5	.0348
c	Rhine at Bale	6.89	1.22	6.38	69.7	.0300
d	Isar, Bavaria	6.05	2.50	7.18	58.4	.0352
e	Salzach	4.26	1.80	5.15	58.8	.0326
f	Limmat, near Zurich	3.16	2.75	5.35	57.4	.0313
g	Saare, Canton Berne	2.70	3.33	4.56	48.1	.0360
h	Rhine, in Canton Graubunden	2.92	6.00	4.23	31.9	.0485
i	Rhine, in the Domleschger Valley	2.95	7.96	7.42	48.3	.0366
j	Kander, Canton Berne	4.12	9.18	8.69	44.7	.0430
k	Plessure, near Chur	4.58	9.65	13.75	65.4	.0294
l	Rhine in the Rhine Forest	1.21	14.20	6.03	46.0	.0309
	Average	....	....	....	54.4	.0357
m	Ravine du Sud, Haiti	5.50	3.22	7.49*	56.3	.0360†

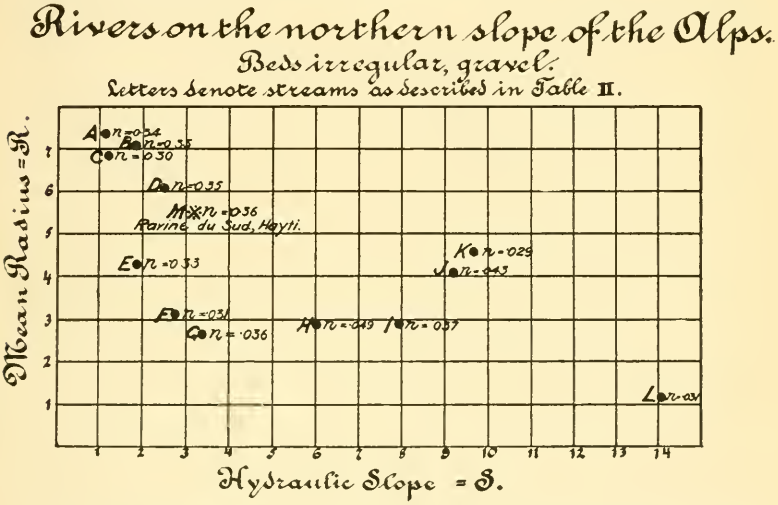
The beds of the above streams are described as consisting of coarse gravel and detritus.

From the measurements of *R*, *S*, and *v* there have been computed the values of the general co-efficient *c* in Chezy's formula and the co-efficient of roughness *n* in Kutter's formula. The former vary from 31.9 to 69.7, and average 54.4. The latter vary from .0203 to .0485 and average .0357. Here as in many other cases, it will be observed that *c* varies much more than *n*, and that the latter therefore offers a corresponding advantage when an assumption is to be made for a new case. I have assumed it in round numbers at .036 and from it obtained for the Ravine

* Assumed. † Computed.

du Sud, $c = 56.27$ and $v = 7.49$. Stevenson's formula, as modified by Mr. Crowell, respectively gives $c = 106.6$ and $c = 14.18$. The coefficients directly determined from the above gaugings, if applied to this ravine, therefore differ almost 100 per cent. from those of Stephenson's formula. In other words, according to this formula the channel of the Ravine du Sud is supposed to carry almost twice as much water as the qantity calculated from Alpine gaugings for similar channels.

This case again shows the danger of using formulas beyond the limits of the experiments from which they were derived.



W. E. Merrill, M. Am. Soc. C. E., writes:—The problem presented at Les Cayes is similar in character to those that have recently occupied so much attention in the French Alps, and similar effects on a small scale can be observed where streams flowing from the hills of our western river valleys suddenly emerge into the flat bottom land through which the rivers meander. It is a well-known hydraulic law that when a stream, heavily laden with matter in suspension, changes its velocity, a certain amount of this material is dropped, and similarly when a velocity, that is just sufficient to carry down stones, becomes lessened, the stones cease to travel. There is such a marked likeness between the phenomena exhibited by the Ravine du Sud and those reported by French engineers, that it may be worth while to compare the two cases.

According to the latter a mountain torrent always exhibits three different phases: First.—The receiving basin, which is funnel-shaped with various irregularities, and terminates at the bottom in a neck or spout. Second.—The discharge channel or gorge, whose features are less strongly marked than the other two sections, but which is noteworthy

as exhibiting neither scour nor deposit. Third.—The area of deposit, where the washings are arranged according to regular laws; it lies at the mouth of the gorge, and has the shape of a hill or flattened cone of gentle slope.

This description of a torrent in the French Alps is exactly paralleled by that given by Mr. Crowell of the Ravine du Sud, except that, owing to the violence of tropical storms, the upper part of the discharge channel or gorge is filled with rocks and the width is correspondingly increased. The receiving basin is the area above Camp Perin, the rocky part of the discharge channel extends from Camp Perin to Carrefour Fondfrede, the unchanging port of the discharge channel extends from Carrefour Fondfrede to the crossing of the Route Torbeck, and the area of deposit extends from the latter point to the sea.

The specially objectionable section of a mountain torrent is always the cone of deposit, as this occurs where land is susceptible of cultivation, and where overflows are destructive. It is here that the stream ought to be regulated and brought between insubmersible banks. After years of study the French engineers came to the conclusion that it was practically impossible to regulate the lower section of a torrent as long as an unlimited supply of traveling material came from above; moreover the mountains were being denuded, the soil and loose rock were washing down on the plains and the violence of the floods was increasing. They therefore determined to begin at the head, by first regulating the torrents in the upper sections.

The first step was to create a number of artificial falls by the construction of masonry dams. These not only destroyed a considerable percentage of the velocity of the flow, but also served as catch basins to collect debris, thus transforming the bed of the stream in the vicinity of a dam from a gulch with precipitous sides into a flat bottom, which would serve as a footing for the side slopes. The next step was to grade and reforest the side slopes of the basin of reception. Finally innumerable low dams, wattlings and plantations were placed, wherever they could cause deposits or check surface washing. The dam across the torrent Riou-Bordeaux has a height above the bed of the stream of 26 feet, with foundations 15 feet deep, so that the total height of masonry is 41 feet. Its length is 274 feet, the thickness at the crown is 10½ feet, and at the base, 18¾ feet. The apron in front of the dam is 46 feet wide, and the total cost of the dam was $20 000.

The effect of these works was to cut off from the area of deposit the supply of waste material, and, after this was done, it became possible to give the torrent a regular bed across the cone, and to confine it between definite banks. It is stated that after the works above named were completed, it for the first time became practicable to build a bridge over the torrent Riou-Bordeaux where its area of deposit was crossed by a national highway.

Unfortunately it does not seem financially possible to apply these principles to the regulation and correction of the Ravine du Sud, and moreover the physical difficulties are probably greater than those encountered in the Alps. I have no doubt that Mr. Crowell has done all that the means available would permit, but judging from the experience that I have quoted, the disease has only been checked, not cured. Deposits must continue to be made in the lower section of the ravine, and space must be made for the water either by systematic excavations between the embankments, or by continual increments to their height. The object to be attained, if possible, is to maintain to the sea the velocity of the second section of the ravine; if this were done there would be neither scour nor deposit until the sea is reached.

As the paper does not give a longitudinal profile of the ravine, I have endeavored to make an approximate one from the contour lines shown on the plan of the town and its environs. This would indicate that there was a decided irregularity in the slope of the ravine, which is unfavorable to the conservation of velocity. These conditions seem to show that there is an opportunity to help matters by establishing uniformity of grade, which might be done by excavating the high parts of the bed, or by building levees of extra height where the grade was less than the average, trusting to the stream to complete the work.

The paper calls attention to the fact that, in addition to protecting the town and surroundings from inundation, it is of the first importance to see that its harbor is not destroyed. The shape of the bar that now closes the port would indicate that the resultant of the littoral currents was to cause a drift of bar material to the east. If this inference be correct, any discharge of detritus west of the town is greatly to be deprecated, and it would be justifiable to incur heavy expenditure to discharge the material into the Islet River. The data contained in the paper are not sufficient to enable a person not familiar with the ground to decide on the practicability of this suggestion, and the subject may have received full consideration, but as the references in the paper are limited to possible diversions into streams lying west of the Ravine du Sud, I have thought it worth while to lay some stress on the desirability of making the Ravine discharge on the east side of the town.

Mr. Franz A. Velschow, C. E., writes:—It seems hardly possible to be able to speak with much certainty about an undertaking like the present without having personally gone over the ground itself or without having more detailed data to go by than those contained in this paper, but I happened some years ago to have to deal with a somewhat similar case of floods on the Island of Viti Leon, Fiji, where the conditions of rainfall show the greatest resemblance to those mentioned in this paper. The following discussion of the plans proposed by Mr. Crowell is based on my experience at Fiji.

The project of providing a channel by means of excavations for the

more or less unknown quantities of water which may be expected with floods, seems to me a somewhat unusual and risky measure to take; and the great expenditure it would involve may not be warranted by the advantages obtained. Such a channel could hardly be expected to be of great permanency, but would give rise to constant repairs, owing to the great velocity of the current, unless the whole channel was set in cement or at least very carefully paved. As it is only required to prevent the ravine from overflowing one of its banks, the danger of flood might be averted by protecting the weak points of this bank with properly constructed levees, leaving the flood to take its natural course and spread as much as it pleased on the outside of these levees. That this has been attempted before and without success, may only show that the extent of the floods had been underestimated, and to form anything like an adequate idea of the proper dimensions for these works of protection, it might be highly interesting to inquire about a description of these recently destroyed engineering works. Were they intelligently designed and what were their height and profile?

While the idea of widening the present river bed by excavations may be perfectly justified by the peculiar circumstances of the case, although I can hardly think so, it is when Mr. Crowell maintains the necessity of giving the ravine an outlet into the sea different from what it has now that I find some serious objections to his project. The object of changing the outlet of the ravine or river (a measure which is always a precarious one and apt to lead to most unexpected complications, as only too many engineers are able to testify by their own personal experience), is a two-fold one: (1) to prevent the harbor from silting up by sediment brought down by the ravine so as to form a bar across it such as the "Barre Nouvel;" and (2) to prevent future floods from cutting a passage through the root of the wharf and thereby menacing the business front of the city.

We have here before us the case of a wharf having been built at the mouth of a river, which wharf afterwards called into existence the town Aux Cayes, as indicated by the very name of this town, and there can be little doubt that the break in the beach line (or the deep water in a comparatively sheltered position which originally caused the wharf to be built in this particular place as a convenient place for shipping), has been caused and maintained by the scouring effect of the waters from the ravine. If, therefore, we cut off the ravine from the harbor, what will become of this place as a shipping place? Surely the beach will soon be found to stretch uninterruptedly across the harbor; as ocean beaches always have a tendency to do when there is no flow of water from inland to prevent or counteract it, owing to the sands being constantly shifted by the coastal currents. As a result, after the inhabitants of the town for some time have enjoyed security against floods as provided by Mr. Crowell's project, they may some day wake up to another

certainty, namely, that their wharf upon which the *raison d'etre* of the town depends, is standing high and dry on the sea shore. They would, therefore, either have to move the town, or construct another pier right out into the ocean and exposed to the heavy breakers, which would be very expensive indeed, and not afford such conveniences for shipping as a wharf in a more sheltered position affords. In other words, the cutting off of the ravine from the harbor, means to do away with or give up the naturally favorable conditions for shipping which the place formerly possessed. It is maintained that the Barre Nouvel is being formed of sediments from the ravine, but even if this could be proved actually to be the case, it does not follow that such a bar would not be formed whenever the flow of water from the ravine ceased; and the shape and location of this bar shows that it is not a river bar, properly speaking, but a reef or an ocean bar caused by the shifting effect of the coast currents upon its sands; in fact, this bar appears to be a commencement of the continuation of the sea beach across the outlet, which I have just predicted would take place when the ravine was completely cut off from the harbor.

No doubt, when the wharf was built the deep water caused the current from the land to run in a direction parallel to the wharf. Since then the situation has become slightly altered, and at present it appears from the map that the current is taking a direction in under the wharf, instead of running parallel to it. But it is an easy matter to force the current into its former direction by turning the wharf into a close wall or pier. As a preliminary measure, this could be cheaply effected by driving a row of close-set piles along either side of the wharf. By the current from land being deflected by this obstacle, the scouring would secure deep water along the wharf, and remove the outer or nearest end of the bar, while what remained of this bar would advantageously act as a breakwater. The current from the ravine would be still further guided to advantage by the building of a bulkhead line from the root of the wharf parallel to Rue de la Duane until across the mouth of the Regnaud River, which river or creek of course ought to be filled in, and the drainage of the town led directly into the sea through a system of pipes. The current from the ravine being thus guided, I confess I am not able to imagine how it could endanger the root of the wharf or the business front of the town. On the contrary, what force the current still possessed after having spent itself on the comparatively flat land above the town, I should consider an advantage, instead of a danger, by its scouring effect on the bottom in front of the wharf.

Having hereby briefly advanced my views in opposition to those maintained by the distinguished author of this paper, I should feel happy if they might aid him in finding a possible *juste milieu*, that would satisfactorily solve the difficult problem now before him.

Mr. Crowell also looks into the question of explaining the conditions

of rainfall which cause the floods at Aux Cayes. As already mentioned, the conditions of the Island of Hayti reminds me very much of those of the Fiji Islands, which I had an opportunity of investigating, and this similarity is particularly striking with regard to the conditions of rainfall. By drawing a comparison, we may therefore be able to throw some fresh light on this subject. The Fiji Islands are situated at the same latitude south as Hayti lies north, and both places are mountainous. Now, nearly all mountain islands similarly situated, show the marked peculiarity of possessing what is called a windward side, with superfluity of rainfall nearly all the year round, while the "leeward" side suffers from scarcity or uncertainty of rainfall. Upon examination it has been found that the rainy side of these islands is turned towards the adjacent cyclone track, the location of which again depends upon the location of the great trade-wind centers. As far as Hayti is concerned the cyclone track of the North Atlantic trade-winds center lies generally to the north-northeast of this island, and the consequence is that by far the greater number of cyclones which pass in the neighborhood of Hayti have their course lying north of the island. The prevalence of rain on the northern slopes of Hayti may therefore be explained in conformity to the cyclone theory I have advanced before this Society, and the application of this theory I made with regard to the prevalence of rain on the rising slope of exposed coast mountains.

On very rare occasions, however, the North Atlantic trade-winds' center and with it its cyclone track, moves so far south that the cyclones pass south of Hayti. Then everything is reversed for the time being, and the southern slopes of the mountains receive a heavy rainfall, by cyclone after cyclone striking against them, and that is, in my opinion, the time when the City of Aux Cayes is exposed to the danger of floods, if I am justified in drawing an inference from what I found to be the case in Fiji.

Mr. Crowell's observation that "the southern slopes are short and steep and receive little rain, even though the precipitation directly upon and along the southern coast may at the same time be very great," is full of interest, and may be satisfactorily explained as a logical consequence of my theory. When the current of saturated air strikes against the northern slope it is brought under extra pressure, and therefore yields plenty of rain on this slope. By being forced to move upwards the pressure is decreased, and no rain falls while the rain giving layers of air are at this, for them unnatural high elevation (that is, while above the southern slope of the mountain ridge), the moist air having been forced to a higher elevation than warranted by its inherent specific gravity. After having passed the mountain ridge it sinks. The pressure upon it is thereby increased, and by the reaction which takes place when the air is prevented from sinking any further the pressure is still further increased, and according to my compression theory, we might therefore

expect to find increase of rainfall along the southern coast line or further out at sea, as also observed by Mr. Crowell. See Fig. 1.

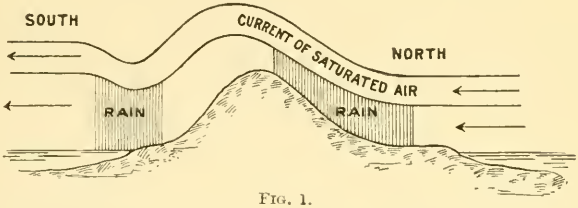


FIG. 1.

On the other hand, the theory set forth by Mr. Crowell that the rainfall on Hayti should be due to moisture collected by the surface air while passing over the 300 or 400 miles wide span of water lying between Hayti and the continent of South America, seem to me impossible to maintain, when it is duly considered that the currents of surface air round the trade-winds' centers pass over thousands and thousands of miles of ocean surface, and in spite of the moisture they may thus collect it never rains within the areas of these centers of high pressure. Let us consider one familiar instance which has direct bearing on this subject. The trade-winds of the North Atlantic pass from the coast of Africa south of the Saragossa Sea and up along the east coast of the United States. When it sometimes happens late in autumn that this current or this center of high pressure advances across the coast line, a period of mild and balmy weather, the so-called Indian summer sets in, and the signal office will predict steady fair weather without rain for New York, as long as these conditions may be expected to prevail. But although it does not rain, the streets become remarkably wet during the commencement of these periods of warm weather. They become covered by a deposit of dew so heavy that even the bright sunshine is hardly able to dry it up until late in the day. The reason is simply this, that the pavement has been cooled down considerably during the preceding period of cold weather, and so dew is deposited when afterwards the current of warm air sweeps over the streets. From considerations like these I should conclude that Mr. Crowell's idea that floods should be caused at Hayti by the moist air from the Caribbean Sea striking against the southern slopes of the mountains which have previously been cooled down by other air-currents, is hardly tenable.

The notion, however, that rain is principally due to moisture collected from the oceans is so ancient and well established, that Mr. Crowell is likely to find a great majority in favor of his theory. It should, in the meantime, be remembered that the evaporation from water-surface is very significant compared to that from cultivated land, and I may finally mention an observation made by Professor Cleveland Abbe in the report of the Chief Signal Officer for 1890, that "the evaporation from salt water is only one-third or one-half that from fresh water." This

observation I have not noticed mentioned any where before, and if it is correct it may be worth while to consider what a difference it would make as to climate in general, if the oceans contained fresh water instead of salt, before we conclude that the evaporation from the surface of the oceans is the main and immediate source of rainfall.

Mr. J. Foster Crowell, M. Am. Soc. C. E., replying to Mr. Hering.—I desire first to thank him for the valuable contribution of the comparative table of formulas for discharge of streams, which comparison cannot fail to be of great service to those of us who in future may be confronted by similar problems; but I do not think his comparison is fair to the Stevenson formula because he presents it not in original form but as modified (by me) for an entirely different purpose than to obtain the amount of discharge, as I shall explain. Without that modification and as stated by Stevenson in his work on rivers,* it would give for the case worked out by Mr. Hering $v = (14.18 \times .65) = 8.2$ for its minimum as against 7.49 by the Kutter formula, a difference of less than 10 per cent. instead of nearly 100 per cent. as when modified. In this connection I would point out anew that under the circumstances cited in the paper it was neither possible nor necessary to know exactly what the total discharge of the stream at flood might be; the desired end being the determination of the dimensions of a new channel, which should have an equal or a greater capacity than the existing channel—the one that was measured—which had proved sufficient for former floods and must continue to be as far as can be known the measure of all future floods. The formula in this case becomes a measure of comparison for channels of different slopes, and I fail to see any danger in the use of the Stevenson formula for this purpose; had the object been to measure the supply of water, neither the method nor the formula would have been permissible. The reason for the modification was to allow for a large frictional effect in the new channels under somewhat slower velocities, but not to minimize the result obtained from the consideration of the present channel; or, in other words, the comparison between the present and the proposed channels is modified in favor of the latter to the extent of 33 per cent. capacity, *ceteræ paribus.*

Certainly extreme caution is called for in dealing, in anticipation, with a flood of unknown magnitude, and the Stevenson formula is consistently conservative from that point of view; and not only so, but the values obtained from it and adopted for the areas of the new channel follow with close conformity the values as deduced from the Kutter formula, as will be quite easy for any one to verify for himself. As a matter of interest I have prepared Table No. 3, giving the two sets of results in parallel columns, using in each the data stated in Mr. Hering's discussion and employing in the Kutter formula the values given by Mr.

* The Principles and Practice of Canal and River Engineering. By David Stevenson, F.R.S.E., Edinburgh, 1872.

Hering in Table No. 2. To make the comparison logical I have added to the Kutter results 25 per cent. after computation. The similarity of the two sets is of course to be expected within the narrow range of velocities in this case, although Mr. Hering's condemnation of the Stevenson formula would predicate very different results. But this is not a battle-ground for formulas, and lest I should be mistaken for an advocate of this class of formulas as against the greater refinement and exactitude of formulas with variable co-efficients, of which the Kutter is undoubtedly the most precise and elegant, I desire to explain that my object is simply to show by the figures that the use of the former is entirely suitable in this case.

TABLE No. 3.—(CROWELL.)

REQUIRED CHANNELS FOR THE RAVINE DU SUD.					CROSS-SECTIONAL AREAS.	
Compartment.	Fall in feet per mile.	*R*	*n*	*c*	Values by Kutter Formula.	Values by Crowell's modification (for this particular case) of Stevenson's Formula.
Typical Section..	17.	5.5	.036	56.2	* 569 square feet.	* 569 square feet.
No. 1.....	26.5	4.5	.036	53.896	† 660 "	673 "
No. 2.....	17.	4.5	.036	53.913	† 824 "	837 "
No. 3.....	15.	4.5	.036	53.926	† 872 "	880 "

* Measured. † Increased 25 per cent.

The suggestion, as to the possible diversion of the Ravine du Sud into the Islet River, made by Colonel Merrill, is interesting to the writer as being the plan he was most hopeful of before visiting the locality. There are, however, three separate reasons which I shall proceed to point out, why it is impracticable, each one of which would be potent by itself. In the first place, the littoral current is from the east. Aux Cayes is near the western end of the Bay of Cayes and is protected from the open sea on the south by the Isle de Vache and smaller coral islands, between which and the main land to the westward, is a narrow channel navigable for small ships, but avoided by ocean steamers on account of the direction of the littoral current. Discharging the waters of the Ravine through the Islet would be fatal to the harbor far to the eastward of the limits of the present inquiry. In the second place, the Islet River is a silt-bearer, and while its current is too feeble near its mouth for it to be a serious source of danger to the harbor at present, it is silting up its own narrow bed to an extent to utterly exclude it as an available channel for the Ravine. Thirdly, to direct the Ravine to the Islet would require a large and costly dam across the present Ravine, and extensive dikes and levees at the north end of the Quatre Chemin which has always been the most vulnerable point in the city to floods.

Extensive excavation would be required for a considerable distance and the lower section of the new channel would pass through a salt water marsh.

Replying to Colonel Merrill's other suggestion, a very valuable one, as to the desirability of securing uniform fall for the new channel, I would say that it is unfortunately true that the profile is too hollow to render this possible without diking to a height and extent that could not be justified by either prudence or economy.

Replying to Mr. Velschow, it is not unnatural, considering the absence of detailed information in the original paper as to the harbor conditions, the situation of Aux Cayes with reference to the sea and the chronology of the wharf, that my friend Mr. Velschow should unwittingly have misjudge the indications of the harbor contours, and have been led to the conclusions he advances. As a matter of fact, however, the wharf, a very slight wooden pier on slender piles, and of very modern existence; it having been rendered necessary two or three years ago because the harbor had shoaled so much at and across the mouth of the Ravine du Sud, that the lighters which always previously had been used, could no longer be floated to the beach. The foreign merchants in self-defense built the wharf, and as cheaply as possible. I may remark in passing that it has since been extended to deeper water, for the reason that the bar is making toward the east, and that eventually, unless the present causes are checked, it will have to be abandoned altogether for a new wharf in another part of the harbor, at the east end of the town. In my reply to Colonel Merrill, in this discussion, I have alluded to the situation of the city with reference to the sea, and stated that the littoral drift is from the east—the Bay of Capes is land-locked on the west.

Mr. Velschow further has fallen into the very natural error of supposing the Ravine du Sud in its present position and condition to be a factor in scouring and maintaining the harbor. While this might be true for brief periods during floods and at long intervals, yet usually the force of the feeble current of the Ravine is expended before it reaches the tidal compartment, at a point rather more than half a mile above the *barre nouvelle* and some distance above the confluence with La Coquette, which is a tidal stream. But there are many small freshets having force sufficient to bring the silt into the harbor and deposit it where the stream meets and is overcome by the wave action.

It is, I think, quite apparent that the Ravine cannot be an agent to improve this harbor under any circumstances, and should discharge outside of it. Since the paper was written I have been informed that a small flood actually did cut through the root of the wharf and threatened the business part of the town, as I intimated was possible, but the force of the flood was not sufficient to affect the *barre nouvelle.*

In regard to the primary source of the rain-fall in Hayti, I frankly admit that I may be entirely in error. Whether the heavy clouds which

come rolling in from the Caribbean and accompany the rain, are produced there or are brought from the far northeast by cyclonic action I have no means of verifying or of contesting Mr. Velschow's views; but when we consider the uniformly excessive rain-fall along the west side of the Caribbean, on the Central American coast, and bear in mind the higher temperature of those waters, we cannot easily eliminate them in our minds from rain producers. Moreover, the cyclones blow every year, the southwestern limits of the storm centers of the North Atlantic cyclones are usually in the Bahamas, the south coast rains in Hayti are common, certainly are annual, but the floods are infrequent.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

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(Vol. XXIV.—June, 1891.)

THE NOZZLE AS AN ACCURATE WATER-METER.

By JOHN R. FREEMAN, M. Am. Soc. C. E.

WITH DISCUSSION.

For measuring the discharge of water in moderate quantity and under considerable pressure a simple smooth nozzle, to which an accurate pressure gauge is properly connected, forms an apparatus of great convenience and remarkable accuracy. For instance, the discharge of a pump delivering its water at a pressure anywhere from 5 pounds per square inch upward, can be metered by this means with an accuracy and convenience not excelled by a weir or by any method known, providing that for the case in question it is allowable to discharge the water in the form of a jet into the air.

The nozzle will, I think, on reflection, be granted to be the most portable and compact gauging apparatus, in proportion to its capacity, which has ever been devised for such purposes. The amount of metal, the complexity of parts, the possibilities for accident, derangement of parts or unnoticed source of error, are in this form all reduced to their lowest terms. The nozzle is, moreover, superior to any sharp-edged orifice, in that its effective diameter can be measured with greater precision, and is less susceptible to wear.

The following paper is devoted mainly to an account of some experiments with certain nozzles up to $2\frac{1}{2}$ inches in diameter, made to determine their suitability for this purpose. The experiments demonstrate:

First.—That the co-efficient of discharge of any particular nozzle may be determined with a very high degree of precision, and is practically constant for all ordinary pressure.

Second.—They indicate that a substantial variation in the method of connecting up the nozzle to its supply pipe would cause little or no change in the co-efficient, and therefore little or no error in measuring the discharge.

Third.—The experiments indicate that to meet any special purpose, one can readily construct a nozzle which is merely a machinist's copy of another nozzle that has been calibrated or tested, and without going to the trouble or expense of calibrating this new nozzle, can safely assume a co-efficient of discharge for it, and with confidence that the possibility for error in this co-efficient is well inside the margin of error or uncertainty incident to most hydraulic measurements.

I advocated the use of the nozzle for this purpose in a paper presented to this Society somewhat more than a year ago, and in a foot note to page 331 of the *Transactions* for 1889, reference was made to a nozzle then under construction for use in gauging the delivery of certain rather small pumping engines. It was in connection with testing this piece of apparatus that most of the experiments described below were made. But it is not to this particular form of the apparatus, but rather to the general subject of nozzle-measurement, that I would direct attention most forcibly.

The sketch, Fig. 1, illustrates the form of device with which these experiments were chiefly made, and which was constructed to serve in certain tests of some small pumping engines. This particular arrangement of nozzle was designed with two objects in view. The first object was to obtain a very portable and accurate water meter of large capacity. The second object was to obtain, if possible, a "Siamese nozzle," so called by firemen, which should deliver a smoother, steadier, and more solid jet, than the Fire Brigade gets from such a piece of its "heavy artillery" when constructed of the ordinary form.

The tests showed this first object accomplished in a most satisfactory manner; but in attaining the second, although fairly successful in producing a jet fully as good and indeed probably a little better than I have seen from any other very large nozzle, it was a less smooth and solid jet than I had hoped for, and there was apparently a somewhat greater tendency of drops to detach themselves from the main stream, than is found

with the best fire nozzles of ordinary size, or of about half the diameter of these large ones.

In devising an instrument for gauging alone, a more simple form, more after the pattern of Fig. 5, would answer equally well. In fact, in my experiments on two pumps I have detached the "Siamese," and merely made use of the nozzle and barrel *C B*, Fig. 1; *B* being simply screwed on to the end of a piece of 4-inch pipe.

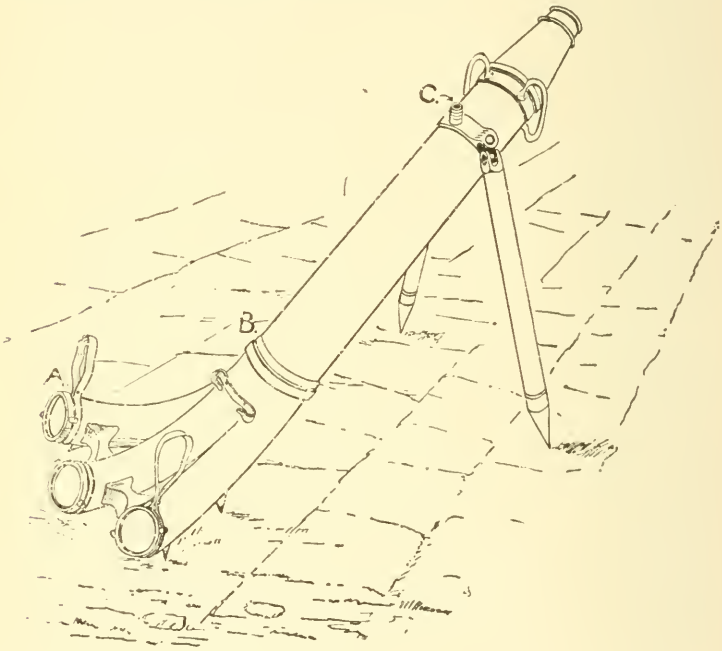

Fig. 1.

Nozzle as used in Experiments 1 to 5.

The peculiarity of this particular Siamese nozzle lay in the great care taken to so shape the waterways where the three streams unite and bend upward, that no whirls or eddies should be produced in the current of water.

First.—The bends upward are circular arcs carefully made tangent to the axis of the play-pipe, and made plain curves, avoiding even the slightest warping or corkscrew-like twist, lest the water current be thereby set rotating.

Second.—The cylindrical cross-section of the waterway of each of the three branches was carefully merged into a V-shaped section where the branches united near *B*, thus preserving a thin partition of metal between each, so the currents do not unite until the straight single pipe is reached at *B*.

Third.—The area of each waterway was carefully and gradually reduced as the branches came together going toward *B*, so that the water moves about 15 per cent. faster at *B* than at *A*. This gradual convergence tends to prevent eddies in the water at the concave side of the bend.

Fourth.—Hollow cross-connections between the three branches at *A* were formed in the casting, so that in case one line of hose happened to be delivering more water than the others, the currents would, under the influence of the diminished area at *B*, tend to equalize, and thus give a more uniformly distributed current in the pipe approaching the nozzle.

Fifth.—To further reduce the liability to twisting of the currents, a thin three-way "rifle-blade," so called, extends from *B* for 16 inches toward *C*, this being set so that the blades halve the current from each of the three branches. At *C* is a hollow ring covering four orifices, and thus forming a piezometer on the same principle as that shown in Fig. 3. The ends at *A* are fitted with ordinary hose-coupling. Claws on the bottom of the Siamese prevent its kicking back; and two light movable props, which can instantly be folded up out of the way and held alongside the barrel, serve to conveniently support it at any convenient angle, as shown.

Some of the subsequent experiments show this elaborate care in forming the waterways within the Siamese was a needless refinement, so far as the object of accurate gauging of flow was the one in view. They had some little value, however, when the same apparatus was to be used to project a powerful fire-stream.

Description of Apparatus, etc.

These measurements were made in the yard of the Washington Mills Company, at Lawrence, Mass. The Lawrence Water Board, through their superintendent, kindly granted free use of the excellent city supply. This was delivered to the site of the experiments by a 16-inch pipe, and under a pressure of 70 to 75 pounds per square inch. The water was led to the nozzle through from three to four lines of ordinary 2½-inch fire-hose, each about 50 feet in length, which in turn were fed from a large four-way Chapman hydrant. The method of measurement of the rate of discharge was by turning on the water to any desired pressure, regulating this pressure by throttling at the hydrant gate, and meanwhile letting the jet discharge freely into the air. Then after all had got into a condition of steady flow, by a slight swinging * of the nozzle-pipe the jet was turned into the hood, by which it was deflected downward into the tank, and a few moments later a reversal of this swinging motion threw the jet free from the tank and into the air beyond.

The jet delivered was caught, and its gallons per minute measured in a rigid and tight rectangular tank, 5 x 8 x 4½ feet deep, constructed

* In cases where the iron cylinder shown in Fig. 5 was used, this was so heavy that it was necessary to keep it stationary, and therefore a light, quick-moving, swinging hood was devised.

of plank and lined with sheet zinc with soldered joints.* The tank set up above the ground level, blocked up on heavy timbers, and together with its drain-pipe, was frequently inspected throughout. It was thus not possible for leakage or waste to escape unnoticed. The horizontal sectional area at various depths was carefully measured, and although the dilation of the tank, due to the pressure of its contents when full, was so small as to be almost inappreciable in the final results, it was measured and compensated for in the effort to guard against error.

The depth was noted by two observers independently, before and after each "fill," by means of a glass tube large enough to avoid error from capillarity, which rested against a very accurately divided scale attached to the side of the tank; and the error in measuring depth of fill could hardly exceed two one-hundredths of an inch, and was probably seldom more than half this.

In manipulating these powerful jets there was sometimes a little water lost by splashing back as the stream was turned into the hood over the tank (this was estimated roughly and compensated for), but as the whole amount so splashed out seldom amounted to more than one-tenth of 1 per cent. of the volume under measurement, there could be no noteworthy error from this source. The area of the tank at various depths was measured independently by different observers.

It would appear that the limit of error in measuring the number of gallons could not be greater than one gallon per thousand or one-tenth of 1 per cent. The length of time occupied by filling the tank to any depth is the element where errors of observation would have the greatest weight; or since in general the duration of fill was only about a minute and two-thirds, or 100 seconds, an error of a single second in measuring this time would have effected the result 1 per cent. At first we relied wholly on a stop-watch for this measurement, and as the observers were skillful, it was thought the error of a single determination need not exceed a quarter of a second, and that the average of a series might be considerably closer. I had some misgivings, however, and so borrowed two other good stop-watches, and in several experiments the same fill was timed by three observers. The nozzle was always swung with a very rapid jerk, and thus the beginning and end of

* This tank was the same illustrated in Figs. 3 and 4, page 315 of the *Transactions* Am. Soc. C. E. for 1889; and the mercury pressure gauge mentioned a little later on is the same as illustrated in Fig. 1, page 308, *idem*.

the experiment were as sharply defined to the eye and ear as could be desired, by the "swish" of the water striking the edge of the hood. But there were occasional unaccountable discrepancies of half a second, or even more, which led me to perfect an arrangement with an automatic chronograph, by which the time was measured with mechanical accuracy to about the fiftieth part of a second.

The operation of this device was beautiful in its perfection and certainty, and a glance at the wonderful manner in which, for instance, Experiments 55 to 62, page 9, repeat the same value for co-efficient, gives ample proof of its satisfactory work.

The electrical contacts were not perfect when we first started the chronograph, or for experiments up to No. 44, although occasionally it served. These contacts and break-circuits were overhauled on September 27th, and after that time (Experiment 46) were perfectly satisfactory.

For the main part of this chronographic apparatus, I was indebted to my friend Mr. William F. Sherman, agent of the Atlantic Cotton Mills, for whom it was devised by Mr. T. G. Estes and originally set up for use in some steam-engine experiments. It consisted principally of a marine chronometer beating seconds, to which Mr. Estes had applied an electric break-circuit, so that in connection with two or three battery cells it would beat seconds on the index of an old-style Morse telegraph recording instrument, and thus as the paper ribbon ran over this Morse recorder, it was indented with a series of dashes at distances of nearly an inch apart along the ribbon and at intervals of exactly a second apart in time. Beside this chronometer index on the Morse recorder another arm or index for marking the ribbon was placed. This additional arm was operated by an electro-magnet, actuated by another pair of battery cells, whenever the circuit was closed by the contacting of two copper plates, one attached to the nozzle, and both so set as to come in contact when the jet from the nozzle was just halved by the edge of the hood leading the water into the tank.

The record made by the chronograph was recorded on the ribbon thus:

Seconds ..... ——— ——— ——— ———

Nozzle movement... — —

and by dividers and scales this space was readily converted into time, probably to within one-fiftieth of a second.

Measurement of Pressures.

These were in every case measured by an open mercury column; and the correction to apply for elevation of center of each orifice above datum of gauge, was determined by filling hose and nozzle full up to center of the orifice, but with no current flowing meanwhile, and then noting reading of gauge. Slight oscillations of the water pressure were continually taking place while the nozzle was discharging, but the variations of the gauges were seldom greater than one-quarter pound between successive observations; and the extreme variation during a whole experiment was very rarely a pound. The ordinary fluctuation was perhaps about half as great as the limits just stated.

The pressure gauges were read each half minute.

Taking all known sources of error into consideration, I do not think it reasonable to suppose that the error in determination of pressure on piezometer could exceed one-half of 1 per cent.; and from a study of the apparatus see no reason why, in the ordinary run of experiments, it could have been over a fifth of 1 per cent.; but on computing the final results, some slight irregularities were developed, which perhaps may have come in through the pressure measurement. The resulting error in co-efficient, which varies as the square root of the pressure, would be only half this per cent. of error in pressure.

The piezometer, or orifice, through which the pressure near the base of the nozzle was communicated to the pressure gauge, when the apparatus was used in form shown in Figs. 1 or 4, consisted of a series of holes of $\frac{1}{8}$ inch diameter, all lying equidistant from each other in a circle around the inside of the pipe. These holes were drilled and finished with care; were normal to the axis, and their inner edges were free from any burr or projection into the pipe. All communicated into a channel $\frac{1}{2}$ inch square encircling the pipe, and which in turn communicated with a $\frac{1}{4}$-inch pipe from which a piece of rubber tubing led to the pressure gauge. Care was taken to free this connecting tube from air bubbles.

The diameters of the three nozzles were calipered by three observers. Thus:

First.—The machinist tried to construct them of the exact nominal diameter.

Second.—They were calipered by means of a Vernier caliper, divided into decimals of a foot.

Third.—The nozzles were calipered independently by another assistant, using a new Brown & Sharpe micrometer Vernier caliper, divided into thousandths of an inch. The resulting diameters were:

Nominal diameter (inches).....	1.750	2.000	2.500
First caliper.....	1.748	1.998	2.500
Second caliper.....	1.748	1.998	2.499

The error in value used, therefore, did not exceed a thousandth of an inch.

The temperature of the water during these experiments was about 69 degrees Fahr. on August 25th, and 64 degrees Fahr. on September 27th.

The various experiments are given in the following table, and are grouped so as to bring all with apparatus of similar form together. The serial numbers will serve to identify their actual sequence. It should be stated that the 2-inch nozzle was the size governing the design of the whole apparatus shown in Fig. 1. The 2½-inch nozzle was devised and added subsequently, as much with a view to pushing the velocity of approach and the velocity past piezometer to an extreme limit, and seeing if they would still serve, as for any other purpose. In other words, the 2½-inch and the 1¾-inch nozzles were not supposed to be so well suited for this special piece of apparatus as the 2-inch, but were devised partly for seeing if the convergence of the cone could be increased or diminished to this very considerable extent, without affecting the value of the co-efficient.

The result was even more favorable than expected.

As still another modification, in order to push the approach of the current into an extreme condition and observe the effect on the co-efficient, we tried a few experiments with the apparatus in the form shown by Fig. 5, except that the tin cone was removed and the water entered the nozzle past the square corner of the brass flange on the head of the pipe. The experiments were made and worked up the same in all respects as those in the tables following.

The results of these three experiments:

Observed pressure, pounds, square inch,	52.04	51.88	20.24
Co-efficient discharge, 2-inch nozzle	0.9870	0.9850	0.9897

Of course it was to be expected that the contraction past the sharp

TABLE No. 1.

Experiments on Discharge of 2-inch Nozzle.

	Serial No. of Expt.	Duration of Fill. (Seconds.)	Observer of time.	Gallons per minute measured in tank.	Pressure shown by gauge at base of nozzle. (Lbs. sq. in.)	Proportional correction to compensate for velocity past piezometer.	Total (static) head on orifice. (Feet.)	Theoretic velocity due corrected head.	Co-efficient of discharge.	Average.	
Aug. 25th, 3 to 5 P.M.	1	85.7	*F*	798.4	41.90	1.0839	104.87	82.13	0.995	.995	Nozzle connected to play-pipe and Siamese, in ordinary normal condition, as shown in Fig. 1. Pressure gauge connected to piezometer at *C*. In Experiments 1 to 5 there were 3 lines of hose leading into Siamese. In Experiment No. 6, 4 lines of hose were used.
	2	104.9	*F*	671.1	29.37	"	73.50	68.76	0.999		
	3	100.7	*F*	665.7	29.34	"	73.43	68.73	0.991		
	4	145.4	*F*	477.4	14.88	"	37.24	48.94	0.998		
	5	139.2	*F*	474.2	14.88	"	37.24	48.94	0.992		
	6	84.7	*F*	848.0	47.48	"	118.83	87.43	0.993		
Aug. 28th, 4 to 5 P.M.	23	89.04 88.9 88.5	Chrn. *B* *P*	760.6	38.36	"	96.00	78.58	0.990	1.0000	Same as Experiment 6, except that wire screen was inserted at *B*, to remove eddies, or stray irregular currents, if any existed.
	24	89.0 89.0	*B* *P*	770.6	38.53	"	96.42	78.75	1.001		Arrangement same as in Experiments 1 to 6, except that the longitudinal diaphragms or "rifle blades" were removed. The screw at *B* was left in as in Experiment 23.
	25	87.53 87.4	Chrn. *B*	769.7	38.52	"	96.40	78.75	1.000		
	26	95.8 95.8	*B* *P*	608.8	24.16	"	60.46	62.36	.999		
Aug. 29th, 4 to 5 P.M.	41	72.0 71.6 71.9	*F* *P* *B*	861.0	48.14	"	120.85	88.17	.999	.998	Nozzle connected to pipe and Siamese, in ordinary normal condition, except that 4 lines of hose were used, as in Experiment 6 above. The pressures were, however, measured by a different mercury gauge from that used in experiments above.
	42	82.58	Chrn.	777.7	39.49	"	98.83	79.73	.998		
	43	98.6 98.6	*B* *P*	672.6	29.54	"	73.93	68.96	.998		
	44	118.7 118.5 118.8	*F* *B* *P*	540.8	19.06	"	47.20	55.39	.999		

Aug. 29th, 3 P.M.	38	74.6	Chrn.	864.8	48.62	"	121.68	88.47	1.000	.997	Pipe *B C* removed, and nozzle attached directly to Siamese, with only a short piezometer intervening, as shown in Fig. 4.
	39	128.3 128.2	*B* *P*	481.4	15.22	"	38.09	49.50	0.995		
	40	128.6 128.0 127.8	*F* *B* *P*	482.0	15.23	"	38.11	49.51	0.996		
Sept. 27th, 2 to 4 P.M.	55	70.45 70.6	Chrn. *F*	850.0	51.45	1.0003	118.84	87.43	0.9950	.9954	The nozzle in these experiments was detached entirely from the pipe *B C*, and also from the Siamese, and was attached to the head of a large cast-iron cylinder, as shown in Fig. 5, with a view to eliminating possibility of error due the high velocity past piezometer in the experiments given above.
	56	72.83 73.0	Chrn. *F*	849.7	51.45	"	118.84	87.43	.9946		
	57	86.16 86.6	Chrn. *F*	749.5	39.85	"	92.04	76.94	.9969		
	58	98.00 97.8	Chrn. *F*	649.1	29.94	"	69.15	66.70	.9960		
	59	122.14 122.3	Chrn. *F*	533.8	20.26	"	46.80	54.87	.9957		
	60	138.50 138.7	Chrn. *F*	459.4	15.01	"	34.66	47.22	.9957		
	61	165.30 165.0	Chrn. *F*	377.0	10.14	"	23.42	38.81	.9942		
	62	228.45 228.3	Chrn. *F*	265.5	5.03	"	11.60	27.32	.9948		The pressure in this experiment was too small to be measured with great precision by the means at hand.
	63	315.1	*F*	179.9	2.46	"	5.68	19.11	.96±.02		

TABLE No. 2.

Experiments on Discharge of 2½-inch Nozzle.

	Serial No. of Expt.	Duration of Fill. (Seconds.)	Observer of time.	Gallons per minute measured in tank.	Pressure shown by gauge at base of nozzle. (Lbs. sq. in.)	Proportional correction to compensate for velocity past piezometer.	Total (static) head on orifice. (Feet.)	Theoretic velocity due corrected head.	Co-efficient of discharge.		
Aug. 28th, 2–4 P.M	18	68.6 68.8	B P	998.9	23.03	1.2341	65.63	64.97	1.005	1.001	Nozzle connected to play-pipe and Siamese in ordinary normal condition, as shown in Fig. 1, except that four lines of hose were used.
	19	67.8 68.1	B P	995.8	23.01	"	65.57	64.95	1.002		
	20	85.31 85.2 85.5	Chrn. B P	783.1	14.29	"	40.73	51.19	1.000		
	21	68.4 68.3	B P	999.7	23.18	"	66.06	65.19	1.002		
	22	70.4 70.6	B P	963.9	21.64	"	61.67	62.98	1.000		
Aug. 28th, 9–10 A.M.	7	68.4	F	996.4	23.49	"	66.94	65.62	0.992	.992	Nozzle connected in same manner as in Experiments 18 to 22, except that a block was subsequently found lodged in one of the branches to Siamese. This obstruction may have caused eddies in currents approaching nozzle.
	8	66.0 66.5	F B	994.3	23.54	"	67.09	65.69	.989		
	9	89.8 89.5	F B	763.6	13.80	"	39.33	50.30	.992		
	10	84.4 84.6	F B	767.5	13.87	"	39.53	50.42	.995		

Aug. 29th, 2 P.M.	33	55.58 55.5 55.5	Chrn. *P* *F*	1154.3	31.25	"	89.05	75.68	.997	.995	Nozzle attached directly to Siamese with only a short piezometer-piece intervening. Pipe *B C*, Fig. 1, being removed, thus leaving apparatus in the form shown in Fig. 4.
	34	55.3 55.2	*F* *P*	1156.0	31.21	"	88.93	75.63	.999		
	35	77.04 77.15 77.0	Chrn. *F* *P*	800.0	15.02	"	42.80	52.47	.996		
	36	62.44 63.2 62.6 62.6	Chrn. *F* *B* *P*	1044.6	25.95	"	73.93	68.96	.990		In this experiment a screen composed of two thicknesses of wire netting was inserted at joint between Siamese and piezometer.
Sept. 27th, 11 A.M.	50	46.15 46.1	Chrn. *B*	1132.0	37.86	1.00075	87.49	75.02	.9863	.987	Nozzle attached to end of a large cast-iron cylinder, as shown in Fig. 5.
	51	49.04 48.9	Chrn. *B*	1130.2	37.64	"	86.98	74.81	.9874		
	52	52.08 52.3	Chrn. *B*	1131.6	37.79	"	87.31	74.94	.9869		
	53	76.34 76.8	Chrn. *B*	820.7	19.91	"	46.00	54.40	.9861		
	54	77.94 77.9	Chrn. *B*	822.2	19.94	"	46.07	54.44	.9872		

TABLE No. 3.

Experiments on Discharge of 1¾-inch Nozzle.

	Serial No. of Expt.	Duration of Fill. (Seconds.)	Observer of time.	Gallons per minute, measured in tank.	Pressure shown by gauge at base of nozzle. (Lbs. sq. in.)	Proportional correction to compensate for velocity past piezometer.	Total (static) head on orifice. (Feet.)	Theoretic velocity due corrected head.	Co-efficient of discharge.		
Aug. 28th, 1 to 2 P.M.	15	111.2 111.0	*B* *P*	590.2	40.29	1.0474	97.44	79.17	0.996	0.999	Nozzle connected to play-pipe and Siamese in ordinary normal condition, as shown in Fig. 1, with pressure gauge connected to piezometer at *C*, 3 lines of hose leading into Siamese.
	16	113.1 113.2	*B* *P*	594.1	40.12	"	97.03	79.00	1.005		
	17	144.0 143.7	*B* *P*	460.4	24.52	"	59.29	61.76	0.996		
Aug. 28th, 11 to 12 A.M.	11	109.7 109.7	*F* *B*	582.1	38.86	"	93.98	77.75	1.001	1.001	Nozzle connected the same as in the three preceding experiments, except that a large block was subsequently found half obstructing one of the three legs of the Siamese, and thus, perhaps, disturbing currents.
	12	113.3 113.3	*F* *B*	582.5	38.91	"	94.10	77.80	1.001		
	13	142.5 142.8	*F* *B*	467.2	24.81	"	60.00	62.12	1.005		
	14	200.3	*F*	350.4	14.16	"	34.25	46.94	0.998		
Aug. 29th, 8 to 9 A.M.	27	99.5 99.4	*B* *P*	680.2	53.38	"	129.09	91.12	0.998	0.999	Nozzle connected directly to Siamese—the pipe from *C* to *B* being now removed—a different piezometer ring (Fig. 3) from that used in Experiments 11 to 17 is also now in use, being interposed between nozzle and Siamese. 4 lines of hose are now in use instead of 3, a wire screen is interposed at joint between Siamese and piezometer section with a view to reducing the eddies due bend and 4 lines of hose,
	28	97.6 97.4	*B* *P*	680.5	53.14	"	128.51	90.92	1.000		
	29	142.9 143.1	*B* *P*	463.5	24.74	"	59.83	62.04	0.999		

Aug. 29th, 11 to 12 M.	30	97.2 97.2 97.2	B P F	699.6	56.42	"	136.44	93.68	0.998	0.997	All circumstances the same as in the 3 observations next above, except that wire screen is now removed.
	31	149.3 148.9 149.2	F B P	467.2	25.08	"	60.64	62.45	1.000		The approach to nozzle is now so probably disturbed by the change of direction and the fourth line of hose that some variation in co-efficient might be looked for.
	32	152.7 152.1 151.6 151.9	Chrn. F B P	360.6	15.17	"	36.68	48.57	0.9922		
Sept. 27th, 9 to 10 A.M.	45	87.6	B	689.3	57.48	1.0002	132.76	92.41	0.997	0.995	The nozzle is now disconnected entirely from Siamese and pipe *C B*, and is attached to large iron cylinder, as shown in Fig. 5, with a view to removing any chance of error due to the very high velocity past piezometer in the foregoing cases.
	46	78.64 78.6	Chrn. B	688.0	57.39	.....	132.53	92.33	0.9959		
	47	100.6	B	576.7	40.23	.....	92.91	77.31	0.997		
	48	103.81 103.6	Chrn. B	576.1	40.28	.....	93.03	77.36	0.9953		
	49	150.0 149.55	B Chrn.	406.1	20.14	.....	46.51	54.70	0.9924		

corner would diminish the co-efficient; but, as showing the constancy of the co-efficient of discharge of a nozzle under different conditions, it is interesting to see that this difference of full 90 degrees in inclination of surface leading to nozzle, as compared with that when attached to barrel *C B*, affected the co-efficient only about 1 per cent.

The compensation for effect of velocity of approach in reducing piezometer readings, was made according to the formula

$$h = \frac{h_1}{1 - C^2\left(\frac{d}{D}\right)^4}.*$$

We can perhaps most expeditiously, as well as most completely, discuss the foregoing tables of the experiments by propounding a few questions, and answering them out of the record of the experiments.

First.—What values for co-efficients of discharge of these three nozzles were deduced from these experiments?

Answer. With apparatus set up, as shown in Fig. 1 or Fig. 5, I finally adopted the value 0.995 for use with each of the three nozzles.

Second.—Can this kind of water meter be relied upon to duplicate its own results?

Is any ordinary accidental variation in method of setting up liable to introduce a change of rate, or error in its indication, while using the co-efficient as previously determined once for all?

Ans. So far as the nozzle itself is concerned, the foregoing experimental values show a remarkable agreement, considering that an effort was made to vary the conditions, and that hardly more than two of the experiments on any page were made under precisely the same conditions as to the method of connection, pressure, etc.

A strong effort was made to vary the conditions, to use now one pressure gauge and then another; to first try one set of piezometric orifices and then the other; to continually vary the pressure on the orifice; to first have the channel approaching the nozzle give the greatest possible parallelism of the fluid veins and then to connect it close to a Siamese, one of whose branches was receiving a double water-supply, and thus undoubtedly causing the water to approach the orifice in a disturbed condition.

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* For the derivation of this formula, see page 456, *Transactions* Am. Soc. C. E., 1889. Also page 476, *idem.*

In the subsequent use of this particular piece of apparatus, as for instance in measuring the delivery of a pump, we may (if our pressure gauge is all right and the apparatus set up in almost any reasonable manner) have the greatest confidence that the error of any series of measurements would not exceed one-half of 1 per cent.

Third.—If a person desiring a circular nozzle for use as a meter should find it expedient to vary the size of the orifice, making it, for instance, three or four or more inches in diameter, and should moreover vary the angle of convergence of the opposite sides anywhere between 10½ and 15 degrees, would he be justified in using the co-efficient .995?

Ans. If for a few inches back from the end there be given to the interior surface a smoothness equal to that which a good brass finisher gives to ordinary lathe-finished work; and if, moreover, the piezometer orifices are carefully made normal and flush with a surface parallel to the axis of the current, and withal so near the nozzle proper that no loss of pressure of importance can intervene; then if pressure is accurately measured, I see no reason why this co-efficient may not be applied with a feeling of entire confidence that the result is within 1 per cent. of the truth.

Fourth.—Will a single constant value for the co-efficient of discharge of a nozzle apply for all pressures, high as well as low?

Ans. The constancy of the co-efficient of discharge under a great range of pressures is well shown by Experiments 55 to 62.

This series of experiments was probably the best of any in the favorable conditions for extremely accurate work. The water pressure was steady; the swinging hood for deflecting water into tank was working smoothly and without splash, and the chronograph was working at its best.

Starting with about 120 feet head of water, and in the successive experiments gradually reducing this head to only a tenth part as great as that with which we started, the variation in the co-efficient between the first condition and the last was less than one-tenth of 1 per cent. For heads below 10 feet, some variation would very likely occur, but no reason appears why the co-efficient for 200 or even 400 feet head should not be the same as for 100 feet.

It may be asked how the various values for co-efficient deduced by the foregoing experiments agree with those of other experimenters, or if they are not unreasonably near to unity; or in other words, if the necessary friction losses would not prevent the actual discharge from being so extremely near to the theoretical discharge as the experiments indicate.

There are no previous accurate experiments on record on nozzles quite so large as these, under such high pressures, so far as the writer is aware. Hamilton Smith, Jr., describes some experiments* on certain very smoothly finished nozzles of cast-iron, about 1 inch and 1¼ inches in diameter, converging from a base of 4 inches diameter in a length of 12 inches. (Angle 15¼ and 13 degrees.) He found an average value of 1.005† for certain nozzles which diverged very slightly at the extreme end, and a co-efficient of 1.006 for one in which the slightly diverging part was cut off, leaving the nozzle convergent at an angle of about 8½ degrees to the very end.

These were tried under a head of about 145 pounds or 335 feet.

Experiments by the writer on a variety of fire-hoze nozzles 1⅛ inch in diameter, gave a co-efficient for play-pipe and nozzle combined of .977.

Certain experiments by Mr. E. B. Weston on a 1⅛ inch fire-hose nozzle gave for the nozzle and play-pipe combined a co-efficient of .975. Obviously the friction loss in the "play-pipe" might account for a considerable part of this difference between .975 and the value .995 found above. I will confess, however, that when upon computing the results of the experiments of August 25th–27th, or Nos. 1 to 44, I could hardly give credence to a co-efficient so near to unity as those obtained, for obviously there must be considerable absorption of head by friction against the walls of the nozzle. There seemed to be no source open for error, unless indeed the piezometer orifices did not, under the extremely high velocity past them, truly reveal the pressure; or unless perchance, the method followed for correcting for velocity of approach, although apparently sound in theory, contained some error.

I therefore connected the nozzles to a conduit so large in diameter that the velocity past piezometer was so small as to remove all chance for such errors, but still got high values for the co-efficient.

In the experiments on smaller nozzles communicated to this Society last year, I showed by certain experiments on the distribution of velocity within the jet, that the lessening of the co-efficient below unity was mainly due to retardation in those filaments of the jet lying close to the walls of the orifice.

I therefore now attempted the measurement of the velocity at various

* Hamilton Smith, Jr., Hydraulics, p. 207; also p. 285–7.

† Greatest possible limit of error thought to be 3 or 4 per cent.

points between center and circumference of the jet issuing from the 2-inch nozzle, and by the use of the mercury gauges obtained a somewhat greater degree of precision than had been secured in the similar experiments of the year previous. For measuring the velocity the same modification of "Pitot's tube" previously described, was used in a similar manner. Fig. 6 shows the velocities revealed at the various points.

It is shown that the issuing water appears to possess its full theoretic velocity at all points from the center of jet out to within $\frac{1}{4}$th of an inch from the side. From thence outward, retardation, due to the friction of walls of nozzle, occurs; but it will be noted that the total amount of this retardation is small in comparison with the whole volume of curve. Integrating this by means of a large scale plotting, we find that the total effect of this retardation at the side amounts to $\frac{65}{10000}$ of the whole delivery, or, in other words, having thus by "Pitot's tube" measured the retardation near the walls of orifice, then assuming this to be the sole cause in diminishing the discharge below that theoretically due the head, we thus deduce 0.9935 for the co-efficient of discharge of the 2-inch nozzle under 50 pounds pressure. This is a remarkably close agreement with the value determined by the entirely different method of measurement in the tank.

It may next be questioned whether the pressure or head can, in general, be measured with reliable certainty by the piezometers, when, as in the apparatus shown in Fig. 1, with the $2\frac{1}{2}$-inch nozzle attached, the velocity past the piezometers is very swift. (This was nearly 25 feet per second in some experiments.)

Darcy first questioned whether or not the height of a fluid column connected through the medium of an orifice like that of our piezometer, gave a true measure of the pressure within the pipe.

Mr. H. F. Mills set out to answer this question by his elaborate series of experiments on orifices in the side of an open trough, and showed conclusively its accuracy for application to an open trough.

Next, Mr. Hamilton Smith, Jr., in his valuable treatise,* though admitting its value for the trough, doubts the value of its application to pipes for very exact measurements; and my eminent friend, Mr. Herschel, in conversation, once called my attention to the possible uncertainty of compensating the indication of a piezometer, past which the water was moving swiftly, by a correction based on *mean* velocity,

* Hydraulics, page 258.

when the velocity of those layers of the current of water next the piezometric orifice was much less than the said mean velocity.

We therefore are justified in extracting from these experiments such information as we can, bearing on the accuracy of thus applying piezometers to closed pipes under high velocities and heavy pressure. The evidence, though not extensive and perhaps not absolutely conclusive, tends to show their great accuracy of indication, and tends to fully justify their use. This evidence is as follows:

First, take the experiments on the 2-inch nozzle with this attached to the iron cylinder, under conditions where the velocity past the piezometric orifice was, at most, only $1\frac{1}{2}$ feet per second, and the head due this velocity only $\frac{1}{3000}$th part of the total head acting on orifice, and compare it with Experiment No. 1 or No. 6, where the velocity past piezometer is 25 feet per second and the head $\frac{1}{12}$ part of the total head. We may, from the fact that the co-efficients as deduced were subtantially alike, reason with justice that the piezometer, with the very high velocity past it, nevertheless told the truth; and we are also justified in believing that the rule followed in compensating for the influence of this velocity on the reading of the gauge was correct. Moreover, although in Experiments 38 to 40, an entirely different set of piezometer orifices and connections were used, the results were still the same.

With those experiments where the $2\frac{1}{2}$-inch nozzle was used, the conclusions as to the general accuracy of piezometric indication and the correctness of the method of correction are still more striking, for here the velocity past piezometer was as high as 29 feet per second and the correction about $\frac{1}{5}$th of the total head. And here again two different piezometers gave substantially the same result.

Nevertheless, although, under these swift currents past them, the piezometers do give substantially correct results, these same experiments perhaps intimate that the method of correction, or possibly the height of the piezometric column, may have been out of the way (too low) by a half of 1 per cent., or thereabouts.

I also had some apprehensions lest the fact that the sectional area of the conduit opposite the piezometers was slightly greater than a few inches up stream where obstructed by the "rifle blades," might throw the piezometer region a little into the condition of a diverging pipe, and thus tend to slightly lower the piezometric column and give an increased value to the co-efficient. Experiments 24 to 26, made with

these blades removed, as also such experiments as made with the aid of the piezometer close to Siamese, show that any difficulty from this cause was not great.

The question next comes, is this apparatus of a form convenient for use?

As to convenience for transportation, the apparatus shown in Fig. 1 to-day lies packed in a common small trunk 12 x 18 x 30 inches; one man can handle it easily, and can in ten minutes take it out and set it up ready for use. It requires no foundation and can set anywhere.

I have with it gauged a pump delivering 1 500 gallons per minute, or at the rate of 2 000 000 gallons per twenty-four hours, under 75 to 100 pounds pressure. I have also used it in similar experiments on two other pumps of nearly equal size and running rapidly, and have in no case found the pulsations of pump to seriously interfere with its use. Ordinarily, I have fed the water to it from the pump through the medium of three or four lengths of common fire-hose. At other times, I have disconnected the play-pipe from the Siamese, and screwed the play-pipe and nozzle directly on to the end of a line of 4-inch iron pipe. For a gauge I have used a thoroughly first-class Bourdon gauge, and have rated this by comparison with a mercury column, or, more conveniently, a Crosby gauge tester.

To answer a question as to what special form I would recommend as a standard for a nozzle meter, it may be said first, that the details of the apparatus are susceptible to great variation without impairment of the accuracy.

The essentials are:

First.—A smoothly tapering nozzle whose sides converge at an angle of somewhere between 5 and 7½ degrees to the axis, and whose interior is smoothly polished for a distance back, equal to say three or four times the diameter of orifice.

Second.—A waterway leading to the nozzle, so formed that the water shall reach the nozzle undisturbed by violent eddies or swirls. This can easily be secured by a judicious arrangement of screens or gratings near the nozzle, even though the converging pipe be crooked, obstructed or unfavorable.

Third.—A well-made piezometer orifice at base of nozzle carefully made flush in a surface parallel to direction of current.

Fourth.—An accurate pressure gauge connected to piezometer by

pipes absolutely free of leakage; and if the water pressure is subject to oscillation, care should be had that the cocks and pipes leading from piezometer give equal ease of flow in both directions, so that action analogous to that of a ratchet and pawl cannot occur and hold pressure, so as to give the gauge a slightly fictitious reading.

A word of caution may be added, to the effect that even the best Bourdon pressure gauges are not instruments of precision unless frequently compared with a mercury column, or preferably, perhaps, a Crosby gauge tester.

Merely as a study I have also sketched out a design for an apparatus intended to cover a large range of capacities, shown in Fig. 7, and a reference to which will serve to illustrate the points which I think should be kept in mind.

The smaller nozzles can be detached, leaving the larger ones in place, and thus securing an orifice of any desired size. Intermediate sizes can be attached to the same base, as for instance a 2½-inch could be screwed on to the end of the 3-inch, in place of the 2-inch shown. The inside corner at the extreme end of each nozzle in the series should be rounded out to lessen the chance of bruising. A straight cylindrical tip of uniform diameter for a length equal to about half the diameter of nozzle is formed at the end of each, and the angle where this unites with the conical portion is smoothly rounded off. The rubber ring for packing the joints in the nozzles is placed at the back end of the joint and held from blowing out by a lip which projects over it. The three screens are for removing swirls or eddies in the approaching current, and the four sheet metal vanes would serve to prevent any rotary or twisting motion. The whole could be secured to supports sufficient to resist the recoil by attachment under bolt heads "A."

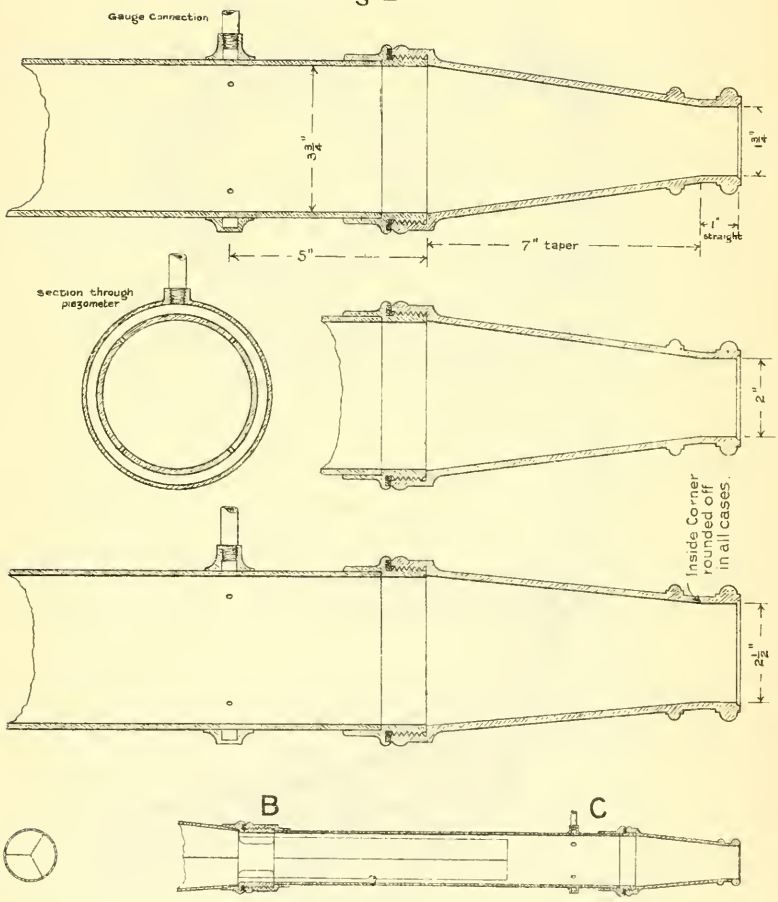
A device like this could be made very light and portable by making the shell of steel plate and the bell mouth of a thin bronze casting. A regulating valve somewhere in the line of pipe to "C" or "B" would serve by partial closing, to throw any desired back pressure upon the pump, and where oscillations of pressure were extreme, an air chamber could be extemporized out of a piece of vertical pipe with advantage, perhaps. Fig. 7 is a somewhat elaborate device to cover a great range of deliveries. Of course, much smaller and simpler devices can be made to serve for special cases.

With the 6-inch nozzle and 75 pounds pressure, this would discharge about 9 000 gallons per minute, or nearly 13 000 000 gallons per twenty-four hours, or 20 cubic feet per second; while with the 2-inch nozzle and 5 pounds pressure, the discharge would be only about 260 gallons per minute.

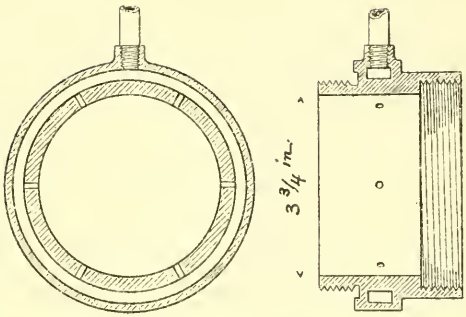
The nozzle may discharge horizontally, or upward or downward, or at any angle between.

In certain pump tests, when discharging about 1 500 gallons per minute and under about 100 pounds pressure, or at the rate of about 2 000 000 gallons per twenty-four hours, I have with great convenience let the nozzle discharge vertically downward into the pump well.

– Fig. 2 –

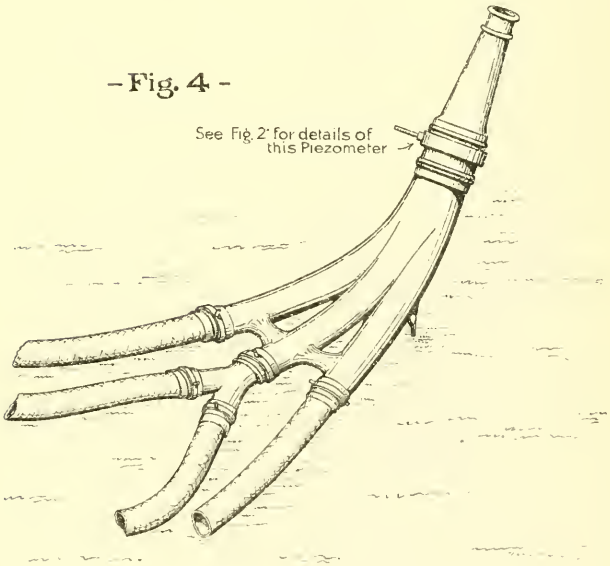

Gauge Connection
5"
7" taper
1" straight
Section through piezometer
2"
Inside Corner rounded off in all cases.
B
C

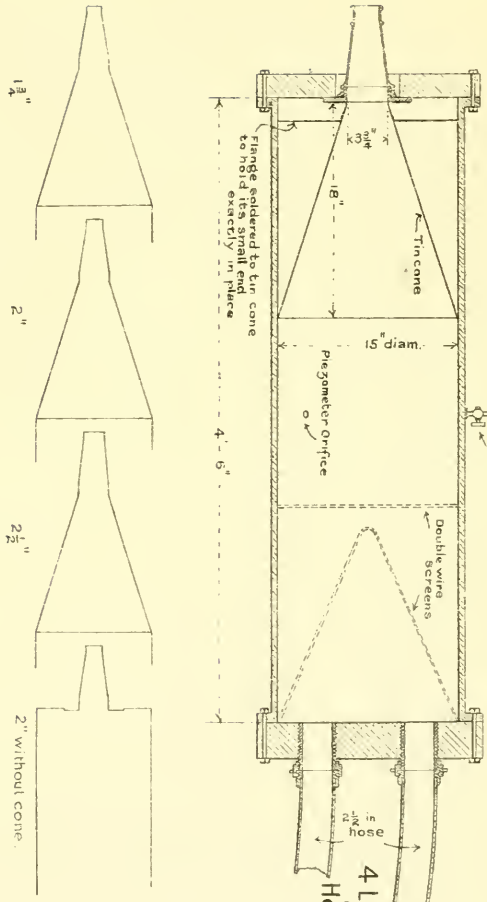
-Fig. 3-



Piezometer Coupling for Measurement of Pressure acting on Nozzle when connected as shown in Fig. 4.

-Fig. 4-

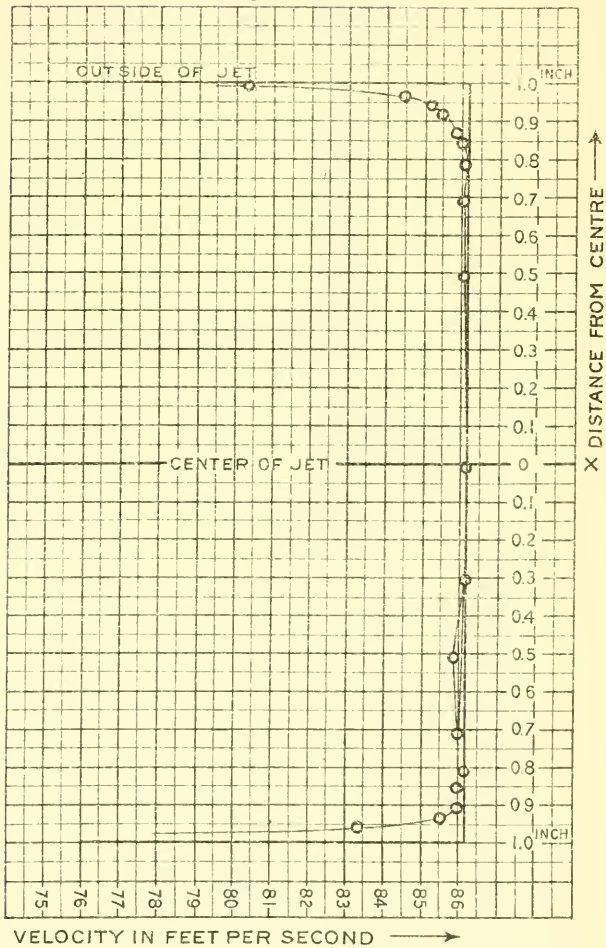


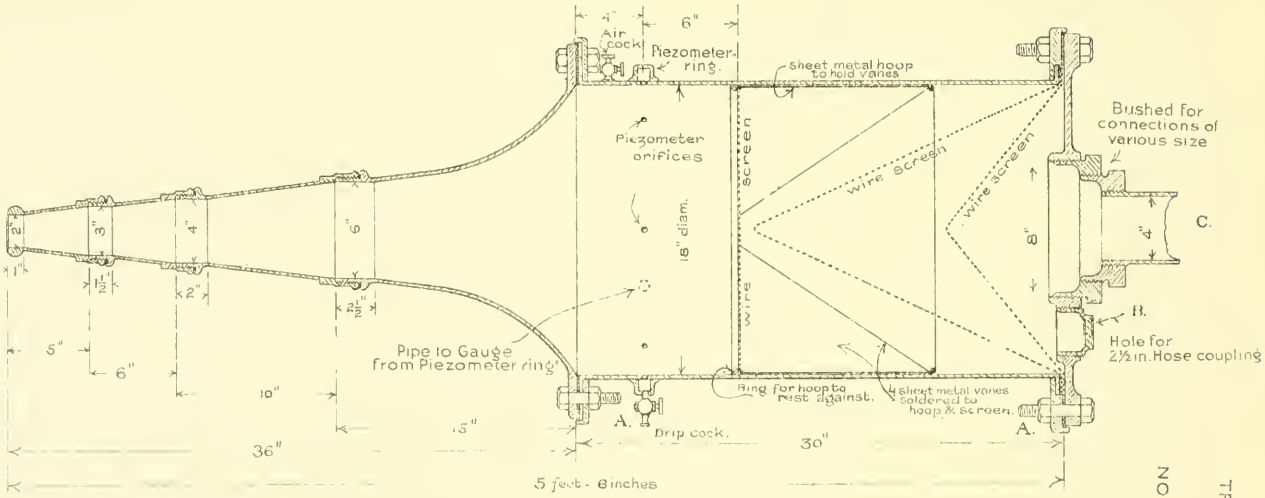

Air Cock
Double wire screens
Piezometer Orifice
15" diam.
Tin cone
18"
Flange soldered to tin cone to hold it at small end exactly in place
4' 6"
4 Lines of Hose.
hose

-Fig. 5-

1¾"
2"
2½"
2" without cone.

— Fig. 6 —


OUTSIDE OF JET
CENTER OF JET
1.0 INCH
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0 INCH
X DISTANCE FROM CENTRE
75
76
77
78
79
80
81
82
83
84
85
86
VELOCITY IN FEET PER SECOND



Form suggested for a Meter Nozzle of large capacity.

Fig. 7.

By placing the nozzle nearly vertical and lowering its end to within an inch or two of the water surface, we found it easy to avoid carrying down much air into the water. If the pump well was not of ample size, and if the contact of the jet with air was not thus reduced to a minimum, the whole of the water in the pump well would quickly have become so full of air bubbles and foam as to greatly interfere with pumping.

DISCUSSION.

William Barclay Parsons, M. Am. Soc. C. E.—In the suggested form of variable sized nozzle, Fig. 7, Mr. Freeman appears to violate his first "essential" for an accurate nozzle, when he lays down the rule that a nozzle should be "smoothly tapering and its interior smoothly polished for a distance back equal to say three or four times the diameter of orifice." In the suggested form there will be at each intermediate nozzle two angles, where the horizontal orifice breaks the regularity of the taper, and also the line of separation where each nozzle is screwed on. It will be noted that the tapering sides are regular for a distance of only 2 diameters in the case of the 4-inch and 2-inch nozzles, and 1½ diameters for the 3-inch.

As to whether these variations are sufficient to affect the accuracy of the measurements is a question that Mr. Freeman can undoubtedly answer. The reason for violating one of his principles of design appears to be to make an apparatus that contains a number of nozzles and thus answers all ordinary cases. It appears, however, that the same end might have been attained by having each nozzle separate and complete, and made to bolt on to the main barrel where the 6-inch nozzle is now fastened. While this arrangement would call for more and larger pieces, nevertheless, they could probably be made as cheaply as the proposed system, as the expensive fittings would be done away with, and certainly all possibility of causing eddies avoided.

Mr. Freeman recommends that the corners of the ends of the several nozzles be rounded to lessen the chance of bruising and so making a rough edge. But to be of practical value this device must be used by persons who may not be particular in watching for the little chances of error that are not readily visible, and who, therefore, may not be sure that each nozzle is screwed down to an absolute fit, with no intervening particles or crack.

The Chair (A. Fteley, Vice-President).—The point seems to be well taken; it is to be regretted that Mr. Freeman is not here to answer these questions; I do not doubt but that, as he will see this discussion, we

may have the benefit of his answers at some future time. You may allow the Chair to say a word in regard to the advantage that I believe the profession can derive from this, if Mr. Freeman is correct, in testing pumping engines. We all know that in testing pumping engines of ordinary capacity it is always quite a question to determine exactly the amount of water that is pumped. I have seen cases where the results were only incomplete, because there was no time or no desire on the part of those in charge to make the necessary expenditures to secure perfect gaugings by ordinary means, and if the proposed methods are as accurate as represented by Mr. Freeman, and from his well-known accuracy I hardly have grounds to doubt it, it would certainly be a great advance in the question of perfect tests of pumping apparatus. It would be of great advantage to secure a perfect and cheap apparatus of this kind.

Mr. Freeman (by letter).—In reply to the suggestion or query of Mr. Parsons, as to whether the successive breaks in the continuity of the convergence of the nozzle sketched in Fig. 7 might injuriously affect the accuracy of measurement, I would say that I do not think that this would be the case. The apparatus shown in Fig. 5 contained similar angles, though fewer, but showed no defect or variation of co-efficient when tested. I may add that I sketched the device here in this particular form partly to bring out the propriety of this very thing, and to indicate the extent to which I considered it allowable to go, should special circumstances render this desirable. I should myself, however, always have a little preference for the single, uniform, uninterrupted taper, whenever conveniently attainable. So long as the angle of convergence is kept within the limits there shown, and while there is nowhere a divergence, I see no reason to apprehend that such changes in convergence or that such small crevices at the joints would induce disturbance in the flow by causing eddies.

Charles B. Brush, M. Am. Soc. C. E.—We are all extremely interested in this subject and in the way it has been treated by Mr. Freeman. It is a serious question, however, with me, whether there is any better way of determining the amount of water delivered by a new first-class pump than by plunger displacement. In a test recently made at Memphis, a very carefully constructed weir was prepared, and the amount of pump displacement was checked very carefully, with the records taken every thirty seconds during two hours, one hour in one day, the other hour the next day. The weir was all right with one exception. The extreme desire of the engineer to have the crest perfectly true led him to delay setting the crest, in Portland cement, until the day before the test. The result was that a frost unexpectedly set in that night and left the surface a little ragged and rough around the brass frame of the weir. He was a very conscientious man, and recognizing the fact that his weir was not entirely correct and true, be proposed not to use it in the test. It was

used, however, and the result was that the pump displacement and the weir measurement differed about 2 per cent. During the second night the frost acted still further on this cement, and made it a little more ragged, so as to make a perceptible curve, and we found on the second test a difference of about 3 per cent.

A well constructed pump is really a large meter, and my experience (when I am sure of the pump as to workmanship, size, stroke, etc.) leads me to receive with a great deal of confidence the records obtained from displacement; and I frankly confess, with more confidence than I do the results obtained from the apparatus proposed by Mr. Freeman. Of course, after a time, the wear of the pump will affect its accuracy, but I am speaking of a new, well-built pump, in good order. In neither the case of the nozzle proposed by Mr. Freeman, nor the Venturi meter proposed by Mr. Herschel, both of which to my mind are based on the same general principle, has there been any practical results obtained outside of their own experiments. I have personally urged that the Venturi meter should be set up and actually tested on a line of water-pipe in regular service. So far as I know, none have yet been tested in that way. I am quite anxious to see it done, and to see the results after considerable periods, and a comparison of the results thus obtained. In relation to Mr. Freeman's apparatus, also, I believe there are none in practical use. I am so much interested in it that I propose to put one up, and in doing so I shall call upon Mr. Freeman to assist me in having it constructed as he thinks it ought to be. It will be attached on a plant near New York, and when in operation I shall be happy to have the members come over and see it. I want to see this thing actually working, not as an experiment, but running for a considerable period of time and under different conditions, such as we usually have on water-works. If we can really rely upon it within 2 or 3 per cent., we have something that is very simple, that is very accurate, and that is very valuable in connection with water-plant operations.

It is extremely important, however, both in the case of the Venturi meter and this nozzle meter that we should be able to get at results quickly and with ordinary men, such as we employ around pumping engines, rather than to employ a corps of scientific men to determine results. If an ordinary engineer who is running an engine at a pumping station cannot operate these meters then they are practically useless. The recording attachment should be so simple that an ordinary engineer can take the record from it, and an ordinary calculator can obtain the results. If that can be obtained it is certainly very valuable and very important.

The Chair (A. Fteley).—Nothing can be more gratifying than to see a member offer to practically advance the question by proposing an actual test, but his statement that the action of pumps is so reliable as to make

of them exact meters is not supported by facts. In estimating the delivery of a pumping engine it becomes necessary to determine as exactly as possible the accuracy of its performance. If the loss of action is 2 or 3 per cent., and if the nozzle meter, which would be very inexpensive, will give an absolute test within 1 per cent., it would certainly be a gain; and as to the necessity for having skilled labor in order to ascertain what the work is, it seems to me that it would be as easy for ordinary engineers to attend to these tests as it would be upon an ordinary test of a pumping engine.

Mr. Brush.—It is my opinion that the pumps to which I have referred recorded correctly the actual discharge. The idea I wished to convey was that the weir was within 2 or 3 per cent. of being correct, notwithstanding its faulty condition.

The Chair.—I understood that.

Mr. Brush.—All weir measurements which depend on a series of questions as to what are proper constants to be used, I rely on less than I do on the accurate measurement of the pump displacement. In relation to the error of 1 per cent., as found by Mr. Freeman, I think the extreme care that was required to obtain this close result might not be observed in ordinary work; and therefore we might not get to so small an error generally. I do not consider the value of these meters to consist alone, or even in greater part, in the fineness of the test of an engine during its first use. I consider their value lies in their power to determine the increase of the slip of the pump. I believe a pump can be constructed so that its record may be relied upon in the beginning, but I do not believe in this record two or three years later. I know there is a slip, and I know that slip increases. I want to know from time to time the amount of this increase. If this apparatus of Mr. Freeman is all right I cannot see any reason why it should not be as correct two or three years from the time it is first attached as in the beginning. If we can obtain correct results on pipes delivering from 2 000 000 gallons up to 13 000 000 gallons per day, the results should be true up to 200 000 000 gallons per day, and therefore we may be able to ascertain accurately how much water is delivered in large conduits.

Mr. Freeman (by letter).—In reply to the suggestions of Mr. Brush that a well constructed pump is of itself, while new, a high grade water-meter, I most heartily concur that this is generally true. There may, although but seldom, be grave exceptions, however, and as Mr. Brush has stated nearly at the close of his remarks, the slip of a pump is likely to increase with age. My friend Mr. Coggeshall, Superintendent of the New Bedford Water Works, stated a good instance of this a year or two ago. As I now recall it, they had been making some computations of the cost per million gallons pumped with one of their engines. They figured the gallons by plunger displacement, and the result showed a most gratifying economy, and, better still, the degree of economy

seemed to increase as the engine grew older; but this struck Mr. Coggeshall as a little too good, so he put in a weir as a check on the pump, with the result of showing that a most excessive slip had developed, due to disordered valves. That weir remains, and an occasional test of the slip of the pumps is regularly made, and the pumps overhauled if the slip is found excessive. And this means of conveniently determining the slip is considered a most valuable auxiliary.

In discussing the report of a committee of the American Society of Mechanical Engineers on a proposed standard method of conducting duty trials of pumping engines, a few months since, I tried to call attention to some of the sources of error possible when using the pump as its own water-meter. Briefly, some of these are:

First.—Backflow of the volume immediately under the lifted valves at end of stroke. In a pump in good order this is small, but if the valve motion should happen to be slow by reason of feeble springs, or inertia of valve, or if valve motion had become sluggish through friction of valve on its stem, this backflow under the valves might be large.

Second.—Although the water cylinders of a pump may be opened and valves found clear, both before and after a trial, a twig or other obstruction may catch under a valve and work out again during a test and leave no sign of the slip it has meanwhile caused.

Third.—Air snifted into the suction purposely to ease the hammer of the pump, or leaking in through some imperceptible and unknown crack may, by causing an imperfect filling of the water cylinders, make the displacement utterly untrustworthy as a measurement of the discharge. I am interested to note in Mr. Holloway's discussion, reference to one more case where something of this kind has happened in practical use, and the record of the pump as its own meter been found untrustworthy.

Fourth.—If a pump cylinder happens to be formed with a cavity from which the air does not get swept out by the water, the alternate compression and expansion of this air may give a fictitious value to the displacement. Even the taking of indicator cards from the water cylinder may not give conclusive evidence as to the absence of air, if speed is high or water hammer excessive. Moreover, the incomplete filling of water cylinders on high-speed pumps, with restricted suction passages, is by no means rare. In the course of some of my experiments made only a month or two ago, we found a Knowle's Duplex 18 x 9 x 12 inches which actually delivered 35 per cent. less water than the displacement called for, due mainly to a leaky suction; and a good Worthington duplex fire-pump 18½ x 9¼ x 10 inches was found, which at high speed, from some peculiar cause not yet determined with certainty, delivered 25 per cent. less water than the plunger displacement. In recent careful trials of five other pumps, each of about 1 000 gallons per minute capacity, I have found the total discrepancy less than 4 per cent., and for large, new, slow-moving, pumping engines, I should expect that perhaps

nineteen times out of twenty the total slip would not be more than 3 to 5 per cent.

If we are testing a water-works engine we do not want to rely on something which is merely *probably* correct or *reliable nineteen times out of twenty*, but we desire to have a convenient and handy method which is absolutely certain, and as free from hidden mysteries as is the measuring of a square packing-box with a common two-foot rule. Therefore, I believe that when there is much at stake we should not use the pump as its own meter, but should obtain external evidence by means of either the weir, nozzle, or Venturi meter, and the nearer either of these comes to the standard of simplicity and certainty just mentioned, the better it will be.

I feel very grateful toward Mr. Brush for his proposition to install a large meter nozzle in connection with a large water-works pumping engine, and shall look forward with great interest to its trial.

John C. Trautwine, Jr., Assoc. Am. Soc. C. E.—Mr. Freeman has handled his subject so thoroughly and well in his paper recently read before the Society, and has made out so good a case for his nozzle-meter, that but little room is left for discussion; and all that I propose this evening is to suggest what appears to me to be some fundamental resemblances, and some structural differences, between the nozzle-meter and others that have recently been suggested, and to point out some of their respective advantages and the special applicability of each form.

The nozzle, as used by Mr. Freeman,* and earlier by Mr. Edmund B. Weston,† for the measurement of flowing water, is simply a special case of the general one represented in the Venturi meter developed by Mr. Herschel and in Pitot's tube. The general case is that where the head generating (or destroying) an observed velocity through a pipe or orifice is measured, and the co-efficient c obtained for the formula—

$$v = c\sqrt{2gh}$$

where v is the observed velocity and h the head producing or destroying it. In Pitot's tube, the head destroys the velocity; in the others it generates it. With the nozzle, discharging into air, the pressure at the orifice is simply that of the atmosphere; so that the head h in the formula is simply the height of the water above the orifice, plus the head due to the velocity past the piezometer; while in Pitot's tube and in the Venturi meter, the orifice is submerged, and the head h generating or destroying the velocity is therefore the difference between two heads; one corresponding to that measured in the case of the nozzle, and the other acting directly at the orifice and in the opposite direction. In Pitot's tube this second head is always positive, and must therefore be deducted from the first; in the Venturi it may be either positive, zero or

* *Transactions* Am. Soc. C. E., November, 1889, and the present paper.

† *Transactions* Am. Soc. C. E., November, 1884.

negative, and in the latter case the true head is the arithmetical sum of the two.

All three of these instruments have the great advantage that the co-efficient is very nearly constant, and almost exactly equal to unity; and each apparatus would seem to have its particular advantages for special cases. Pitot's tube is the only one of the three that can be conveniently applied to open channels; the Venturi meter commends itself as a permanent attachment to existing systems of water supply; while the nozzle is well adapted to tests of pumping engines or of fire-hose, has the important merits of simplicity and portability, and (as compared with Pitot's tube) of solidity and consequent freedom from liability to damage. On the other hand, Pitot's tube has a much wider range of applicability. While it is the only meter of the three that is well adapted to the gauging of open streams, it may also be used to good advantage in the spheres of usefulness of the other two. Mr. Freeman has used this remarkable instrument to excellent advantage in his delicate determinations of the velocities in different parts of the cross-section of a hose or nozzle, and M. H. Bazin has recently applied it to perhaps equally delicate and interesting investigations respecting the distribution of the velocities and pressures in the sheet of water passing over a weir.

The development of Pitot's tube from the simple forms proposed by its inventor into that of a most convenient and accurate meter appears to be due to Professor Stillman W. Robinson, M. Am. Soc. C. E., of the Ohio State University, who describes the instrument in detail in *Van Nostrand's Magazine* for March, 1878, pages 255, etc. In the same journal for August, 1886, he describes its application to the gauging of currents of air or of gases.

It would be of great theoretical interest, and perhaps of practical utility, if piezometers were to be established at points close together along the nozzle and play-pipe in experiments like those of Mr. Freeman, so as to give a plotting of the heads, showing their variation between the orifice and the base of the play-pipe. A comparison of Mr. Freeman's earlier experiments, in which the heads were measured at the base of the play-pipe, and the present series, in which it was measured at the base of the nozzle, shows (as might be expected) a much greater uniformity and closer approximation to unity, on the part of the co-efficients, in the latter case; and the question arises, to what extent (if any) can we increase the accuracy of the nozzle meter and its reliability with widely varying forms of nozzle, by placing the piezometer still nearer to the orifice?

Mr. Freeman (by letter).—In reply to Mr. Trautwine and his reference to the work of Professor Robinson in developing the Pitot's tube into a convenient gauging instrument—I would suggest that probably the most extensive practical application of the Pitot's tube ever made in this country or abroad was made by Mr. Hiram F. Mills, Chief

Engineer to the Water Power Company, at Lawrence, Mass., and that his work antedates that of Professor Robinson. Twenty years ago Mr. Mills constructed several of these instruments, some on the general plan of that illustrated in the large work of Darcy and Bazin, but embodying several improvements of much value in practice, and made careful and elaborate determinations of their co-efficients. These instruments were used for many years, and are, perhaps, still in use, for gauging the volume of water supplied for power to some of the large manufacturing corporations at Lawrence, and their indications served as the basis of settlement between seller and buyer in contracts amounting to many thousands of dollars. It takes a good deal of care and skill to manipulate an instrument of this sort so that error shall not creep in, but in the hands of a skillful and experienced observer they will do very fair work even with velocities down to 3 feet per second. Mr. Mills also made many other special researches with apparatus on this principle. No account of these experiments has been published, a fact much regretted by all familiar with their range, accuracy and value.

In reply to Mr. Trautwine's final suggestion, I would reply that I think we now have got the piezometer up as near to the orifice as it is worth while to go—for one leading consideration in the effort to increase the accuracy, is to keep the velocity past the piezometer low; hence it should be back where the area of channel is large. And since our total loss of effect is but 0.005 this comes as near to a co-efficient of unity as we need try to attain.

Professor J. E. Denton.—The matter of tests of pumps is an interesting subject to me, and I will mention one or two facts that have come under my observation. I understand Mr. Freeman's nozzle is an attempt to make a portable substitute for a weir. He does not impeach the accuracy of the weir, nor do I understand that he improves on the accuracy of the weir by this device. It is hard to see how one could do otherwise, when it is understood that the rate based upon the measurement of water in large quantities, for any such calibration as Mr. Freeman has made, could not for a moment sustain the comparison to weir measurements. The nozzle, so far as he has calibrated it, is entirely reliable within the area that he states, which I gather to be about 1 per cent., but I think he has not undertaken yet to calibrate a nozzle larger than 2 inches, and that is equivalent to calibrating 2 000 000 gallons in twenty-four hours. That is a small approach to handling the quantities that are called for in our tests of pumping engines.

Also I understand Mr. Freeman's nozzles have yet to be calibrated under the pulsations of water that are always present with pumps, and that his 2-inch nozzle has only been calibrated under a steady stream, so that we must allow for the accuracy of his work until he has calibrated under a pulsating stream. Admitting the accuracy of this, however, we may say that his 2-inch nozzle is an experiment that we can

accept for such small pumps as he has applied it to, and under two million gallons. Unfortunately, the testing of the water of those pumps is seldom a matter of importance; the tests we want are the larger ones for cities. I doubt if we can accept the statement that a calibration of these nozzles can be substituted for pump or weir measurements. I believe Mr. Freeman has only claimed for the nozzles the advantage of their portability and the quickness and ease with which they can be erected; but when it comes to the test of a large pumping engine, and it is decided that a large quantity of water is to be measured more closely than the use of the pump and indicator cards would give—and I believe their limit is about 2 per cent.—can we trust the nozzle measurement? (It is pretty well established that where the stroke is constant, the difference between the pump and the vertical displacement of the plunger is something inside of 2 per cent.; if the stroke is variable that brings it beyond 2 per cent.) The crank pump, of course, settles its own case. The direct-acting pumps vary in their economy. The crank pumps have practically a positive stroke; I believe they work within a 16th of an inch in 36 inches, so that most experts in pumps are quite sure they can determine whether the pump is safe, within 2 per cent. Granting that this nozzle, on a small scale, has been proved to be as reliable as a weir, still it is yet to be tested in measuring as large quantities as have been measured by a weir, before we can entirely regard it as a substitute.

Mr. Freeman (by letter).—Before the present century, or indeed, probably since the time of Torricelli and of Newton, it has been recognized that the discharge of a simple orifice, nozzles included, could be computed approximately if its diameter and the head acting on its base were known, but the method has heretofore had but little, if any, "professional standing," so to speak. The remarkable capabilities for accurate water measurement possessed by the nozzle came to my notice two or three years ago, and so far as my opportunities have permitted, I have labored to establish the high accuracy of this method of measurement on a firm and scientific foundation. I have not taken the time of the Society by recommending merely a method which promises well, but have already put its working to the practical test up to a fairly good practical size, and have tested it not merely under most favorable conditions, but have, as will be seen by studying the experiments, sought to vary the conditions and to disturb the approaching current—to try nozzles made at different shops—to test them under wide ranges of pressure and of extreme velocities past the piezometer, and finally have used the nozzle as a practical means of gauging, in some pumping engine tests which, while trying to perfect a style of pump for fire duty, I have had occasion to make upon some half a dozen different moderate sized pumps in different cities, set under widely different conditions and some of them running under extreme conditions of speed, water-hammer and violent pulsation. Un-

der all these trials the nozzle has fully met the requirements, and my confidence in its accuracy, has continually increased, and proofs of its great practical convenience have accumulated.

For fifteen years or more I have had considerable experience with weir measurements under various conditions, and have witnessed the use of weirs by others for measuring pump discharges, and have used them myself for this purpose, and while I believe that for the measurement of large volumes (say 3 to 300 cubic feet per second), under low heads (say 1 to 5 feet), the weir will probably always continue the standard method; I feel equal confidence that for measuring moderate volumes (say 100 to 5 000 gallons per minute) under high pressures, 10 feet or upward, and where the jet can be freely discharged into the air, the nozzle will steadily grow in favor and become recognized as fully the equal of the weir in authority, as fast as hydraulic engineers have occasion to put its convenience to the trial. I would not, for an instant, be understood as discrediting weir measurement. Weirs are, however, so expensive and inconvenient to apply that it is becoming too common to do without them and trust to plunger displacement.

One great advantage of the nozzle meter over the weir is its portability and ease of attachment, and that one nozzle can be, if so desired, calibrated once for all and then used at many trials. There is, however, no more real need for calibrating each nozzle than there is for calibrating each weir. That one not experienced may get misled in the use of a weir has often been shown. Eddies in the approach, rounded crest, lack of air under the sheet, improper ratio of length to depth, insufficient depth below the crest and measurement of depth down stream from the point where the surface of water begins to curve, have each got good men into trouble. The recent experiments of Bazin (1886–88) on influence of velocity approach, are also worthy of study in this connection.

(See Annales, Ponts et Chausées, October, 1888, or more conveniently, Mr. Trautwine's abstract and translation in *Engineering News*, December 27th, 1890.)

That the nozzle will prove superior in accuracy to the weir is due: 1st. To there being less uncertainty as to the correction for velocity of approach. 2d. There is with a nozzle of the degree of taper recommended, no uncertainty as to the degree of contraction. 3d. A mercury pressure gauge used in connection with a nozzle measures upon a magnitude so much greater than does a hook gauge over a weir, that the relative precision of the former may readily equal the minute accuracy of the latter. 4th. The discharge of a nozzle varies as the square root of the head. The discharge of a weir varies as the cube of the square root of the head. Therefore, while an error of 2 per cent. in determining the nozzle pressure would cause an error of about 1 per cent. in the quantity gauged by the nozzle, the same error of 2 per cent. in the weir depth would cause an error of about 3 per cent. in the quantity indicated by the weir.

The superiority of the nozzle over the Venturi meter, for cases where the jet can be discharged into the air, comes: 1st. From there being but a single pressure to be measured, instead of having to work on the difference of two pressures. 2d. The play-pipe leading to the nozzle can be large enough to give a slow velocity past the piezometer, and thereby the pressure can be measured with greater accuracy than it can at the swift moving current at the "throat of the Venturi," when any little burr or almost invisible projection at the piezometer, or lack of parallelism of current, might cause a noteworthy error. 3d. The magnitude of the quantity measured, and furnishing a basis for the computation, is greater, and may therefore be measured with a higher degree of relative precision.

The degree of precision mentioned by me as attainable, was intended to be a conservative statement, for I am inclined to believe that the discrepancies which appear in Tables 1, 2 and 3, simply give the measure of the degree of precision of the apparatus available to me for observing time and pressure; and the remarkable series, 55 to 62, taken after my electric chronograph was perfected, incline me to the belief that were it worth the while, one could so perfect the auxiliary apparatus of pressure gauge and time-piece (and by using a large tank, and noting effect of temperature); that if the source of water supply was substantially free from pulsations, the very simple meter nozzle shown in Fig. 7, might measure with certainty to within one-tenth of one per cent. In other words, the discrepancies in our values measured for the co-efficient, do not signify that the co-efficient of discharge really varied to this extent. Moreover, the larger part of the observations given in these tables are with conditions purposely more disturbed than they need be in practice. In some the velocity past the piezometer was purposely made extremely high. In others the current approaching the nozzle was thrown into a somewhat disturbed, eddying condition. In all, except when the chronograph was used, the smallness of the tank, together with discrepancies in the stop-watch caused a lack of regularity not belonging to the nozzle as a meter.

It has been suggested in the discussion that a degree of care not attainable in ordinary practice may be needed to get so high a degree of accuracy in the use of a meter nozzle as within 1 per cent. To this I reply that the only great care needed is care to use a pressure gauge whose accuracy or degree of error is known. Further, in reply to Professor Denton, it may be said that I do, for moderate volumes and high pressures, claim for nozzle measurement an increase in accuracy over weir measurement, but that the margin of uncertainty in a well arranged weir measurement is so small that the reducing of this by $\frac{1}{3}$ or $\frac{1}{2}$ is for most practical purposes of less account than are the advantages of compactness, convenience of calibration and portability possessed by the nozzle. The largest nozzle which I have as yet calibrated is $2\frac{1}{2}$ inches

in diameter, instead of 2 inches, as is intimated in Professor Denton's discussion.

The kind and enterprising offer of Mr. Brush will soon give the Society an opportunity to judge of the convenience and accuracy of the nozzle applied to a large water-works engine.

I will return to one point further, which seems to have been lost sight of in the discussion. While questioning if the co-efficients here determined could be used for nozzles of different or larger size, by reminding that if the mere simple theoretical value for the discharge, be used without any co-efficient whatever, the result will still be as accurate as can be attained by any other ordinary form of measurement. In other words, the amount of divergence from the extremely simple, pure mathematical theory, is only one-half of 1 per cent. By the delicate investigation briefly referred to on page 18, and illustrated in Fig. 6, I showed this divergence almost wholly accounted for by the retardation of friction against the walls of the nozzle. Now grant, for argument's sake, that in some other uncalibrated nozzle there was double the skin friction found in any of those which have been calibrated, or grant that the skin friction became trebled by old age or corrosion, the practical error thereby introduced would be probably inside of 1 per cent., or less than is often caused by disturbing circumstances about a weir. And any such roughness as just suggested would be so noticeable that it is hard to conceive of its being tolerated by any competent engineer.

Professor J. Burkitt Webb.—I am sorry that Mr. Freeman is not here, as he might explain a point which I do not understand. Mr. Freeman says, toward the close of his paper: "I also had some apprehensions lest the fact that the sectional area of the conduit opposite the piezometers was slightly greater than a few inches up-stream where obstructed by the 'rifle-blades,' it might throw the piezometer region a little into the condition of a diverging pipe, and thus tend to slightly lower the piezometric column and give an increased value to the co-efficient." As I understand the column, it is a column of water whose height indicates the statical pressure in the piezometer region, so that a lowering of the column means a diminution of the pressure. If, in this region, and by reason of the absence of the "rifle-blades" the section is increased, so that the region is, in fact, the larger portion of a diverging pipe, then, of course, the velocity is diminished, and consequently the pressure must be increased, as also the height of the piezometric column. I have no doubt that the author of the paper will see the (at least apparent) discrepancy, attention being called to it. It is a point, however, which is not understood by many, and it is difficult to convince some objectors of the truth of the theory. If two pipes, alike in all respects, are to be compared, except that in one the velocity decreases by reason of a slight enlargement, while in the other the velocity does not change, then the decrease of velocity must have a cause, and the only

cause assignable is an increase of pressure. The effect of friction and any inclination that the pipes may have, will be substantially the same in both, leaving no other conclusion than that of an increase of pressure where the pipe enlarges. Although we rightly conclude that if the pipe is enlarged it cannot flow full without a decrease in the velocity of the water, yet the enlargement is not the cause of the decrease, but the increase of pressure is. In fact, the only thing that can decrease a velocity is a force in the opposite direction, and this is just what the increase of pressure amounts to, and the water loses its velocity in forcing its way into the region where the increased pressure exists. A steam injector makes use of this principle in forcing water into a boiler where the pressure is greater than the injector, and the water is delivered into the boiler through a diverging tube.

This arrangement of Mr. Freeman's for measuring the flow of water, worked very nicely in a model which I had occasion to make to demonstrate a principle in hydraulics. It is well known that a jet of water issuing from a nozzle exerts a reaction equal to the momentum of the water, but this was disputed, and it was claimed that while a horizontal jet exerted this reaction, an upward or downward jet exerted a different one. The surest way to show the falsity of such a claim is by experiment. Peter Ewart experimented upon a jet of water issuing horizontally from a vessel, and found the law true (see Vol. II, "Memoirs of the Manchester Philosophical Society," or Weisbach's "Mechanics," Vol. I, under "Reaction of Water"), but the experiments with jets in other directions is not so easily made. To weigh the reaction of other jets, say one flowing vertically downward, I constructed an apparatus (see "Franklin Institute Journal," August, 1887, and January, 1888, for cuts and complete discussion), consisting of a tank with an adjustable weir, by means of which the height of the water in it was maintained constant. From the bottom a pipe projected vertically downward, ending in a nozzle of much smaller diameter, from which the downward jet issued. In order to weigh the reaction the pipe was cut a short distance below the tank, and the lower portion supported in position by scales, constructed for the purpose. With the exception, then of the crack, one thirty-second of an inch wide, the pipe was continuous from the tank to the nozzle, and if no water escaped at the crack and no air entered, the desired conditions for weighing the reaction would be obtained. To make sure of this, it is necessary simply to adjust the weir until the head of water in the tank is just sufficient to supply as much water to the hanging pipe as will keep it full, and this is known at once from the fact that if more is supplied it commences to escape from the crack, while if less is furnished air is drawn in and the jet commences to sputter. This crack, therefore, constitutes a simple piezometer for maintaining the pressure at that point in the pipe, equal to the atmospheric pressure, while it also leaves the lower pipe free to

be weighed. The nozzle is first corked up and the pipe weighed full of water, and then it is weighed with the water flowing, the difference being the reaction of the jet issuing from the nozzle minus that of the jet flowing from the tank into the suspended pipe. It seemed very beautiful that the water would jump across the crack, and enter the the lower pipe without loss and without suction, and though the laws of mechanics made me reasonably sure that it should do so, I was surer after seeing it.

Two or three years after making these experiments, we heard of the great things that were to be expected from a new phase of jet propulsion, and I told my students, much to the astonishment of some, that a vessel would go as well with a jet squirting backward into the air as with a submerged jet. One of them got the use of a steam pump, and without telling me until afterward, proceeded to interrogate Nature. He hung up a hose, with a bent nozzle on its lower end, and forced water through it with 100 pounds pressure, measuring the reaction of the jet with a spring balance. In water or out of water the reaction was the same, and when he belabored the jet with a board it didn't stir the hose, nor did holding a board within an inch or two of the end of the nozzle.

The velocity with which a jet issues from a nozzle does not in any degree make it like a solid rod, and such a stream is as incapable of resisting compression as if it had no velocity. It might cut your finger off, but a stream of bullets would do so, or you could get that effect by jerking your finger with the same velocity through still water. In fact, by shooting the same number of rounds of bullets per minute, with the same velocity as the jet backward from a vessel, the same propulsion would be obtained as with the jet.

While the method proposed may be a good way to measure a discharge of water, it would seem advisable in any important experiment not to depend entirely upon any one method if it can be checked by some other, and I would propose as an improvement on the simple nozzle, a nozzle swung up in such a way that the reaction of the issuing jet could be read from a spring balance. This would give the product of the mass issuing per second by the velocity and serve as a check upon the discharge as calculated from the piezometer or the meter.

Mr. Freeman (by letter).—In reply to the first point raised by Professor Webb, viz.: as to my remark near the bottom of page 19, where I was discussing the general question of piezometers, rather than nozzle measurements, and regarding a transitory doubt expressed by me as to a possible slight local disturbance of the piezometric indication, I would say that in a diverging tube with a swift current, the regimen of flow is generally in a kind of unstable condition. The inertia of the swifter moving water tends to drag along the water in the divergence at the sides, and the "suction" on this water tends to produce a vacuum and lower the piezometer, the action being in feeble imitation of the action of the well

known "ejector" pump when driven by a water jet. At one time I feared that this might injuriously affect the reading of that piezometer located under those peculiar conditions. This question has no special bearing on the general subject of gauging by the nozzle.

The main part of Professor Webb's discussion in which he describes his experiments on the reaction of jets, is very interesting to us all, for although theory is clear on these points, it is hard to fully comprehend them and feel sure until the actual trial of such experiments as Professor Webb's. As to measuring the quantity discharged by actually weighing the reaction of a large nozzle, such practical complications would be brought in that I fear no advantage in precision would result.

Some one has raised the point that it requires a delicate computation to interpret the indication of the gauge and give us the information in gallons per minute. If one will construct his nozzle like Fig. 7, so that the velocity past the piezometer shall be slow, the computation becomes one of the most simple of all hydraulic problems. And if once a nozzle is constructed, and its diameter calipered, a table can be easily prepared giving the discharge corresponding to each pound of pressure, so that with the apparatus once set up he can perhaps, all in the short space of twenty seconds, read the pressure gauge, look out the quantity and know the rate of discharge.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

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480.

(Vol. XXIV.—June, 1891.)

PROPORTIONAL WATER-METER, SPECIALLY ADAPTED TO INFERENTIALLY MEASURE THE TOTAL DISCHARGE OF NOZZLES.

By JOHN THOMSON, M. Am. Soc. C. E.

WITH DISCUSSION.

The writer is led to more hastily prepare and present this communication than he had otherwise anticipated, in consequence of the recent paper by Mr. John R. Freeman, M. Am. Soc. C. E., entitled "The Nozzle as a Water-Meter," which, presumably, is the outgrowth of his previous very able experiments, the "Hydraulics of Fire Streams," presented to this Society. As I understand it, Mr. Freeman freely offers this device to the profession for their use, more particularly as a means for measuring the discharge of pumping engines during efficiency trials. Therefore I shall herein combine a short discussion in criticism of Mr. Freeman's paper, and submit in like manner and for a similar purpose a device which, it is believed, is better adapted for the contemplated duty.

Some of the objections to the use of Mr. Freeman's system have already been brought up by Mr. Charles B. Brush, M. Am. Soc. C. E. That spring gauges require to be frequently calibrated is well known. It is also a fact, at least in the writer's experience, that ordinary commercial

pressure gauges are quite as liable to lose their accuracy suddenly as to part with their truth gradually and uniformly. There is not to be forgotten what gauge-makers term "sluggishness under tension," the hand indicating after the impact, and continuing to indicate by momentum, thereafter. Then, too, the accurate reading of the hand of the gauge when under considerable tension is in itself an art. But the controlling objection is that the sum of all the uncertainties, whatever they may be, is not applied to the right-hand side of the decimal point, but to the left-hand side thereof. In other words, an unobserved error of small value as to the gauge may be of great value as to the total discharge. Besides, not alone are the aberrations intermittent, but they depend for accuracy upon acquired personal skill or aptitude, while the error may be intermediate to the observations or synchronous therewith. In this connection I may digress to say that Mr. Emil Kuichling, M. Am. Soc. C. E., has recently found that the use of ordinary pressure gauges in piezometric measurements is quite unreliable, and for such purpose not believed to be trustworthy if accurate work is essential. The means which he has substituted, and the experiments in connection therewith, will probably be presented to the Society by him at a later day.

I may also advert to the fact that one of the particular features of Mr. Freeman's experiments in the "Hydraulics of Fire Streams," was his skillfully designed and accurately constructed mercurial gauge; and that the only results which he himself appeared to question were the experiments with the Pitot tube in which a spring gauge was used.

The device which I herewith present is based upon the well-known principle of proportional measurement of volume, and is in fact an inferential proportional water-meter, although as applied to Mr. Freeman's nozzle it appears in the main but a modification of his arrangement, the pressure gauge being dispensed with and simply an ordinary water-meter substituted. In brief, the scheme or principle is, to deflect a small portion of the whole stream, to measure this accurately, and thus inferentially determine the total discharge. The meter is in truth a gauge recording by quantity, but set under conditions which are believed to be conducive to a much higher degree of uniform accuracy, certainty of action and durability, than in the instance of an ordinary gauge, indicating the dynamic pressure in pounds.

In the accompanying drawing, Plate LXI, which is a partial side elevation and longitudinal center section, the conditions just referred to are

illustrated. The pipe, the nozzle, and the piezometer sleeve, are essentially similar to those shown in Fig. 2 of Mr. Freeman's paper, except that the openings *A*, through the pipe leading to the circular chamber, *B*, of the piezometer sleeve are larger, and that a base, *C*, is provided for supporting and securing the apparatus, as to the timber, *E*. The hub, *F*, of the sleeve is adapted to receive an ordinary union, *H*, which connects directly with the inlet chamber of the meter. This connection also serves as a support to the meter. The outlet chamber of the meter is connected by the spud and union, *I*, to a brass outlet pipe which extends forward, parallel with the nozzle, supported by a bracket secured thereto; the right-hand end of the pipe being bent downward and thence outward, until its open end lies approximately in the center of the line of discharge, *K*, of the nozzle.

Secured to the back of the end of the outlet pipe is a plate, *L*, the bottom of which is formed to a conical tube, *M*; its larger opening presented toward the nozzle, and its restricted opening directed to the center of the outlet of the pipe. The outer and upper extension, *N*, immediately above the conical tube, is finished to a knife edge, the more readily to deflect the water past the sides of the outlet pipe. The tie-rod, between the bracket and the plate, is to stiffen the structure.

It will now be seen that the dynamic effect, capable of being produced upon the meter, may be very great, for the reasons that we have, first, direct pressure from the piezometer chamber to the inlet side of the meter; second, practically a direct discharge into the open air; and third, the suction produced upon the interior of the outlet pipe, due to the water flowing past the outer edge thereof at *O*, and the additional suction due to the water which directly impinges upon and flows through the conical tube, acting in accordance with the principle of the injector to cause secondary flow by induction.

We thus have the necessary conditions—namely, ample difference of pressure between the inlet and the outlet of the meter—to produce in it the most uniformly accurate results as to its operation; which will be when the meter is worked at a fairly uniform rate of discharge and with a maximum duty not exceeding, say, three-fourths of the usual advertised capacities. Such conditions are readily obtainable under the requirements here contemplated, in that the fluctuations of discharge during the ordinary duty test of such engines are comparatively limited. The calibration of the meter may be readily obtained by delivering, at

different rates of flow, into a receptacle of known capacity, or more accurately by weighing the water; when, if the indications made by the register of the meter are uniform, a co-efficient is established to obtain from the fixed automatic record of the meter the total quantity of future deliveries. The function of the stop-cock shown in circuit with the outlet pipe is to assist in such calibration. Thus, with the cock closed the water may be run to full capacity of the nozzle before discharging to the trial tank; and when all is ready, the nozzle may be deflected and the cock opened practically simultaneously. So, too, the flow through the meter may be very quickly stopped without danger of injury from water shock.

In testing meters by short runs it may be well to note that, whenever practicable, a volume should be delivered sufficient to insure at least one complete revolution of the primary hand of the register. This is for the reason that the register dials of commerce are not accurately graduated in the subdivisions of the unit of measurement.

In a calibration of this kind, the first step would be to ascertain and fix the maximum operation of the meter. The limitation may be readily accomplished in the ordinary manner, that is by applying a throttling diaphragm between the outlet spud of the meter and the union. It may also be noted that when the meter is once calibrated the register may be adapted to indicate the total quantity and not the proportional; but as this would be a matter of convenience only, it might not be warranted in practice. The employment of the separate induction tube *M* is not regarded as an element absolutely necessary, and the apparatus might be simplified to the extent of its omission.

As to the type of meter to be employed, the writer does not hesitate to say that under the conditions herein set forth, the light, compact, positive displacement rotary meters would be the preferable; not only because of the convenience in manipulating, but in that they usually have a higher discharging capacity with the least resistance to flow. There are a number of such styles of meters in the market which might be readily adapted to the conditions and duty here indicated and described.

As regards the size of meter, I can think of no advantage likely to come from the use of instruments larger than the $\frac{5}{8}$ inch, $\frac{3}{4}$ inch and 1 inch sizes, to be worked to maximum capacities of say 10, 20 and 40 gallons, respectively, a minute; for the reason that the meter employed

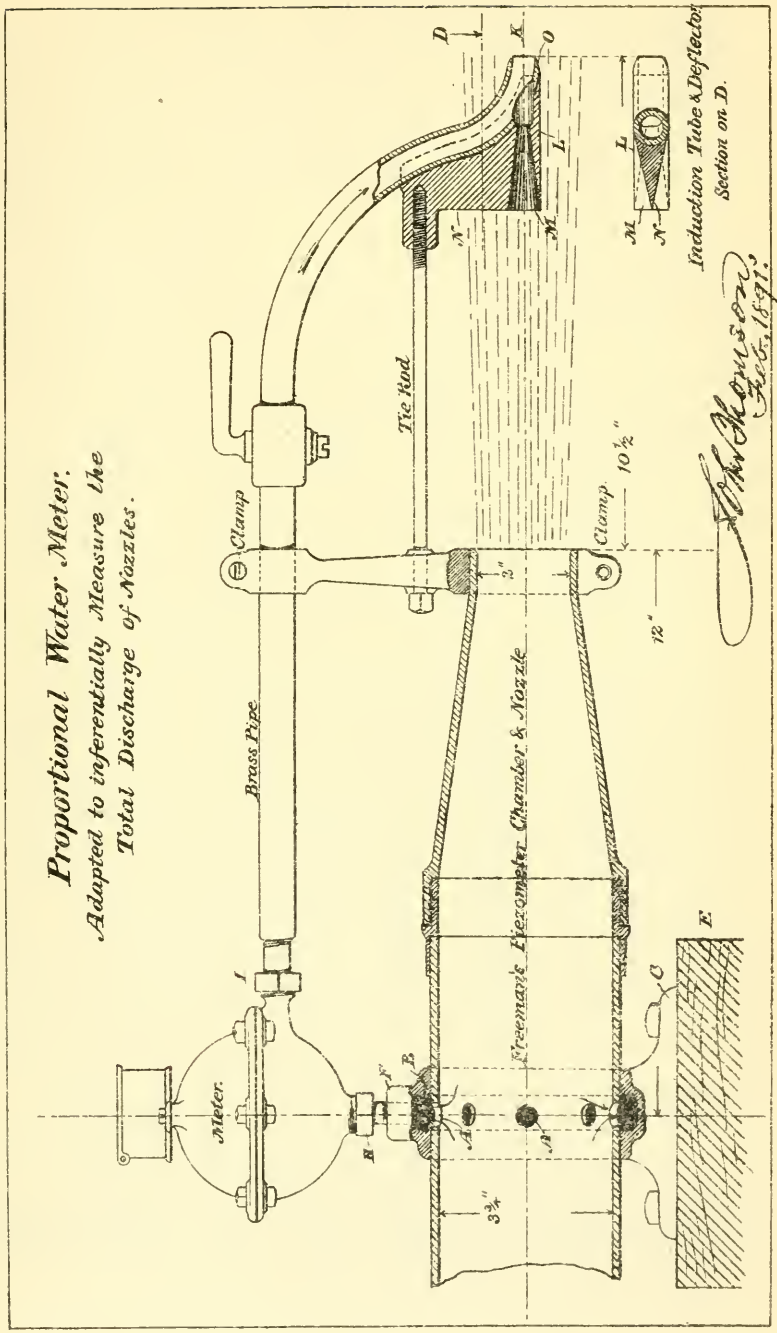
must operate with equal accuracy, whether its proportional value, or coefficient, be as 1 to 10, or to 50, or to 100. The determining factor in the selection of the size, however, might necessarily depend upon the facilities for calibrating.

In conclusion, I deem it but proper to state that although, for lack of facilities, I have not tried this device in actual practice, it is yet not entirely a theoretical deduction, but the outgrowth of the actual application of its essential principles, in the design of proportional water-meters for use under the much more difficult requirements of regular service. And irrespective of the fact that there are here shown some features subject to patent monopoly, I would say that any member of this Society is free to use the same for the purpose primarily specified in this paper.

DISCUSSION.

Mr. Lewis H. Nash.—In some experiments I have made, I was surprised at the accuracy which could be maintained. In my experiments the meter was on a small scale. The meter I speak of was of 2-inch capacity. The attempt was not only to obtain an accurate result with a large flow of water, but to get a meter which, under all conditions of flow, would give a substantially accurate result. In order to obtain a constant relation between two streams of water; you must have some way of obtaining two resistances which will bear a constant relation to each other; so that if you measure one stream you can, with accuracy, determine the other. I found that the difficulties in relation to measuring came principally from the resistance of the measuring devices themselves, that is to say, the meter. You will find that all meters have a certain amount of resistance due to their construction, such as velocity of the moving parts and friction in the pipes which connect the meter; whereas the resistance of the main stream would be a comparatively simple thing. So, if you undertake to force the meter in any sense, the deductions you obtain will be void. I used in my experiments a series of holes of the same size, one of which passed the metered stream and the others of which passed the main stream.

In order to secure accuracy it is only necessary that the resistance to flow through the meter be kept proportionally small, and when you have a difference of pressure driving the water through the orifices, of 2 or 3 pounds, the resistance of the meter is negligible if it is not overforced, and in this case the flow of water through the two channels will be substantially proportional to the rate of discharge of the several noz-


Proportional Water Meter.
Adapted to inferentially Measure the
Total Discharge of Nozzles.
Meter.
Brass Pipe
Clamp
Tie Rod
Clamp
Freeman's Piezometer Chamber & Nozzle
Induction Tube & Deflector
Section on D.
12"
10½"
3¾"
2"
D
K
O
L
M
N
E
C
B
A
F
I

zles. I found that when the pressure at the orifice is 2 or 3 pounds to the square inch, the results are remarkably constant. Of course, the limits to accuracy are something like this: if you force a large quantity through, you will find the resistance increases in the measured channel more rapidly than in the other channels; and if you are measuring very light streams the proportional resistance in the meter channel again increases. This may be due to the stiffness of the water, the water prefers to take the other channel.

I should say it would be a very simple matter if two nozzles were used, one to index the meter in any condition, and the other to take the stream directly. I think you would find the stream discharge was in perfect proportion to the capacity of the nozzles, when the pressure at the nozzle is considered.

Prof. J. E. Denton.—In regard to Mr. Thomson's paper, I am not sure whether it is intended to substitute the meter as a more reliable device than the spring gauge. In one case we have to determine whether the meter is more liable to keep its rate under the shocks of the water than the spring gauge, or we have the set of experiments that Mr. Freeman has made, using the meter as a gauge. Knowing Mr. Thomson's meter, and the other meters of the same class, I have no doubt that it is quite as reliable as the spring gauge, but I cannot see that it helps the general confidence in the meter as compared to the weir, which has been confirmed so many times in the last half century.

Mr. Thomson.—Replying to Professor Denton, I would say that the application of the meter is here intended simply as a substitute for the gauge as a record; it is not a proportional meter as described by Mr. Nash. I think Mr. Nash has made the point very nicely in regard to the condition of flow. I regard it as quite material to success that under the conditions shown in substituting the meter for the gauge, the rate of discharge through the nozzle should not fluctuate very materially, and, as a matter of fact, in conditions of the kind spoken of here, this would not occur; nevertheless it is my judgment, based on some little experience, that the frictional resistance of the meter would be quite as constant as the frictional resistance of the flow through the main nozzle. The standardizing or rating of the meter would depend upon the test measurements. It would be necessary to measure the entire discharge from the nozzle, then simply note the indication on the meter which gives the relation between the two.

The Chair (Mr. A. Fyley, Vice-President).—Do I understand that in your apparatus you take the area of the pipe which conducts water to the meter and compare it to the area of the main pipe?

Mr. Thomson.—No, I have nothing to do with that. I take a pipe, say 3 or 4 inches in diameter, and attach any size of meter, then discharge through the nozzle a certain quantity of water into a tank, and find for a certain quantity of water delivered at different rates of dis-

charge, say possibly at 50 cubic feet a minute or 40 or 60 feet a minute, that for a like quantity of water discharged into the tank there is the same indication on the meter every time. For say 50 feet you find 1 cubic foot on the meter, although the fluctuation in the rate of discharge may vary from 50 to 25 cubic feet a minute; you establish the constant ratio of the indication on the meter to the total quantity of discharge. It is simply the attachment of the meter, the measurement of the total quantity of the water, and then finding out what the relation is by the register of the meter.

The CHAIR.—You have to make a previous experiment by which to find out the full amount of water that is furnished by the whole apparatus.

Mr. THOMSON.—Yes, that is it. I have made many experiments on apparatus that are analogous to this, and at ranges of discharge from 20 to 55 cubic feet a minute there is no variation; hence it is not essential that the flow should not fluctuate. Take a $\frac{5}{8}$-inch meter. I should say it should be operated so as not to discharge more than, say, $1\frac{3}{4}$ cubic feet a minute. There are a number of commercial meters now in the market which may range in discharge from $1\frac{1}{2}$ down to $\frac{1}{4}$ cubic feet a minute, and yet register with practical accuracy.

The CHAIR.—This method would require the constant use of a nozzle of the same pattern, or it would require previous different calibrations. It will require a long series of experiments under different pressures and with nozzles of different sizes, in order to be able to answer any call that anybody should make for measuring water.

Mr. THOMSON.—In all apparatus of this kind—we will say a 3-inch diameter of nozzle with any size of meter applied to it, you cannot take that meter and apply it to another 3-inch nozzle with any certainty of results. Each apparatus by itself would be required to be calibrated by itself.

The CHAIR.—Certainly. I mean to say that if you are to be ready to answer anybody's call to gauge water with that particular nozzle, you would have to try the whole apparatus under various heads in order to know just what it does; it might happen in practice that you have such conditions to meet, and if you are called upon to measure quantities of water different from what that nozzle could measure, each should be tried in the same manner so that you could be sure of your results.

Mr. THOMSON.—That is it exactly. I am simply suggesting a substitute for Mr. Freeman's gauge, a meter which in my opinion, is more accurate than the spring gauge. I am not proposing it as a commercial meter; but when calibrated under conditions such as set forth by Mr. Freeman it is more accurate, in my judgment.

The CHAIR.—Then I was mistaken, because I believe Mr. Freeman suggests his apparatus as a commercial apparatus; you do not put yours on the same basis.

Mr. THOMSON.—No, and I do not understand that he does; I did not suppose that Mr. Freeman had any such intention.

J. C. TRAUTWINE, Jr., Assoc. Am. Soc. C. E.—I understand Mr. Freeman as claiming that any nozzle of ordinary commercial form and in good condition will give without calibration fairly approximate results with the formula:

$$r = 0.995 \sqrt{2\,gh}$$

in which h is the pressure shown by a piezometer placed at the base of the nozzle.

The proportional or inferential meter suggested by Mr. Thomson in his paper now presented, while it also depends upon the pressure at a point in the supply pipe a short distance back from the orifice, requires no measurement of that pressure, or of the velocity through the orifice, but depends simply upon the establishment of the ratio between the total quantity discharged and the readings of an ordinary water meter through which is passed a small portion of that quantity. It is thus seen to be radically different in principle from the meters referred to in my discussion of Mr. Freeman's paper, and it is much to be desired that Mr. Thomson will put his suggestion to the test of practice and communicate the results in a later paper.

The CHAIR.—It is my recollection that Mr. Freeman went so far as to state that he could guarantee those results within a small percentage, providing the angle is within certain limits and providing there are no irregularities in the nozzle.

Mr. TRAUTWINE.—My recollection was that any ordinary nozzle could give satisfactory results without calibrating.

Professor DENTON.—I think Mr. Freeman's nozzle cannot be used quite so freely as that; as I understand Mr. Freeman, there are some very delicate calculations before you can use it; I do not think this apparatus can be used any more often than the weir can.

Mr. J. F. HOLLOWAY.—I think the point is well taken in regard to the nozzle method of measuring the flow of water. It seems to me rather questionable whether accurate measurements can be made by frictional resistance alone. Accurate measurements I think must take place by the displacement of something solid. The method which Mr. Thomson presents here is simple, as he says; being a device by which he hopes to obtain a better result than by the use of the spring gauge, but the whole apparatus depends largely on the condition of the outlet nozzle, and I think that it would be quite unsafe for anybody to assume that any nozzle of a given dimension would invariably produce certain results. We know, and there are some here who may remember, that in the old hand fire engines great care was exercised in having the interior of the nozzle not only constructed on the best lines but kept in the very best order, and that the care of the "nozzle" was always a sacred trust; it was always kept most accurately as to its dimensions and its bore

polished to the highest degree; this was regarded as an essential feature of the old hand machine. Now a nozzle may be damaged in some way by corrosion or otherwise, or it may be by the action of dirty water passing through it, and if so, it would upset the nicety of adjustment which is so essential to accuracy of results.

As to measuring the amount of water discharged by means of a nozzle, it strikes me as an excellent way of doing it, either as carried out by Mr. Freeman or with the variations proposed by Mr. Thomson. The comparisons made by Mr. Trautwine are interesting, and prompt me to add one more. To calculate the current (which, we may suppose, is too large to be measured directly) flowing in any electrical conductor, we need to know simply the fall of potential, or electro-motive force between two points and the resistance of the wire, and if the latter remains the same, the current varies with the fall of potential. But we may avoid a direct measurement of the difference of potential by "shunting" off a portion of the current, sufficiently small to be measured, and causing it to flow in a parallel wire between the same two points; then the current in the main wire will bear the same ratio to the current in the shunt as the resistance of the shunt bears to that of the main wire.

Mr. Freeman's plan corresponds to the first method; he measures the difference of pressure which causes the flow through a nozzle when resistance has been previously determined, and from this difference he calculates the discharge. Mr. Thomson proposes to follow the second method and shunt off a portion of the flow, measuring it by means of a meter and deducing the whole discharge from the registration of the meter. The only difference between Mr. Thomson's plan and that used by electricians is that the resistance of a homogeneous wire of uniform section is a simple thing to measure, and therefore, the calculation of the current is correspondingly simple, while, in the case of the water flowing through a nozzle, and through the meter and its connections, the channels are neither of uniform section, like the wire, nor homogeneous, if we may apply that term to a channel in which the resistance varies inversely as the section; consequently the calculation of the flow cannot be made on the principle, if the ratio of the resistances and the whole apparatus with meter attached has to be calibrated, so as to find by experiment the ratio between the discharge through the nozzle and that through the meter.

Professor Webb.—In reference to the last paragraphs of Mr. Freeman's paper, where the nozzle is supposed to discharge "into the pump well," does any one know what the effect of the entangled air in the water is? Such air is in the shape of bubbles, so small as to be practically invisible, and it seems to me it would increase the apparent duty of the engines. Would it not do so? It would be very difficult to tell how much air there was and to make a correction for it.

Mr. Holloway.—It is much easier pumping air than water. There

was some discussion at one time as to the quantity of water that was pumped in a trial of engines in a western city, in which the superintendent of water-works claimed that an immense amount of water had apparently been pumped by the engines as measured by plunger displacement, but which, in fact, was far less, owing to the admission of air under the suction valves. I think, very likely, the presence of air in this case would greatly reduce the flow of water through the measuring nozzle.

Mr. Fteley.—Was the fire put out a little quicker in the case you speak of?

Mr. Holloway.—I think its only effect was in the showing of the annual report of the superintendent.

Adjourned.

Mr. Trautwine (by letter).—I had no intention of claiming, on Mr. Freeman's behalf, that a nozzle of any shape and in any condition will give accurate results, but merely that any ordinary shape in good condition would give usefully approximate results, and that this is within Mr. Freeman's claim appears, I think, from a reference to the answers he makes to questions 3 and 4 on the 16th page of his paper.

I did, however, omit to refer to the correction for velocity of approach (I do not remember any other) required by the piezometer readings. But for this correction * Mr. Freeman gives a formula (page 15), so that no calibration is required on this account; and the point which I wished to make remains established, viz.: That whereas Mr. Thomson's differential nozzle meter absolutely requires a special calibration, at least for every change in the relative capacities of the nozzle and the meter, Mr. Freeman's pressure nozzle meter, under the reasonable conditions specified in his paper, would ordinarily require no calibration.

John R. Freeman, M. Am. Soc. C. E. (by letter).—In discussing the interesting contribution of Mr. Thomson to the study of nozzle measurement, I would first state that my ideas as to the special value of the nozzle for a means of gauging, apply almost solely to its use for tests or measurements of comparatively short duration and not for integrating a long continued flow. I do not regard the nozzle as possessing any special merit for this latter purpose, except it be observed by some persons at frequent intervals. Precisely as with the weir, the nozzle is an excellent device for exhibiting the rate of flow, and like it, is not specially adapted for use in connection with mechanical devices belonging to the present state of the art to give a record of the aggregate flow, where the greatest accuracy is desired. For such accurate measurements as in an engine test, where the nozzle meter might naturally be used, I regard the attachment proposed by Mr. Thompson as involving a sacrifice of simplicity and as introducing possibilities for error.

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* Within the range of Mr. Freeman's experiments the correction in the head did not reach 25 per cent.; corresponding to a correction in the co-efficient of about 10 per cent.

Thus: *First.*—With regard to the orifices *A*, if a current is steadily drawn through them, as proposed by Mr. Thomson, they at once lose their distinctive character as piezometers, as the term is ordinarily understood.

Second.—On account of this current, a twig or leaf or small obstruction would be more liable to get caught in the piezometer orifice, and thus deflect the current toward or away from it.

Third.—By the addition of the meter a serious complication is added, for the proportion of whole current which will pass through it depends, as with electrical currents, on the resistance of this shunt. Any little thing such as wear, corrosion, or a grain of sand which would in nowise seriously interfere with the accuracy of this meter itself and not affect the accuracy of a meter under ordinary conditions, might seriously affect the ratio of the two currents, by increasing the frictional resistance to flow through the meter.

Fourth.—Any corrosion, obstruction or change of resistance within the brass pipe, stop-cock, or deflector, would change the proportion of the measured current to the main current as just previously described.

I fully appreciate the desirability of the good thing toward which Mr. Thomson is striving, and for one am grateful for his effort to help us get there, but for the extremely rigorous conditions of such tests as a duty trial of a pumping engine, believe that I can see possibilities for trouble which would destroy any feeling as to certainty of accuracy, even though an instrument of the kind proposed should make a good showing during its trial and calibration.

Almost the sole feature as to which serious question may be raised in the use of the nozzle as a meter or on which doubt may be thrown, is that as to the accuracy of the gauge. I have had quite a good deal of experience with Bourdon gauges of various makes, sizes and kinds, and know that even the best test gauges do sometimes get strangely deranged. The question of securing accuracy by a Bourdon gauge is by no means hopeless, as the many refined investigations continually being made in steam engineering by their use plainly shows. In the most rigid and exacting duty trial, the Bourdon gauge on the nozzle will measure pressure just as certainly and accurately as will the Bourdon gauge on the steam pipe, and indeed with greater accuracy, for as previously pointed out in the paper, one per cent. error in the gauge leads to but one-half of one per cent. error in the computed flow. In any important work in either steam or water, all Bourdon gauges should be often tested. Mere comparison with a standard gauge is not fully satisfactory.

In the paper I referred to the Crosby gauge tester. This is a very simple device made by the Crosby Gauge and Valve Company of Boston, and listed at $50. It consists simply of a piston very accurately finished to ¼ square inch area, and surmounted by a scale-pan on which weights

can be placed. Its piston cylinder is filled with oil and communicates by a pipe to a screw coupling to which the gauge under question may be attached. The great and peculiar merit of the device is found in the way the effect of piston friction is annihilated by simply spinning the scale-pan and piston while the load is on. This rapid rotary motion lets the piston seek its true level free of the effect of friction. The whole device occupies less than a cubic foot of space, and is tenfold quicker of manipulation in gauge testing than a mercury column, and is superior to the ordinary mercury column in accuracy. It can be calibrated absolutely at any time by merely a ten-pound weight and a micrometer caliper, with no disturbing question as to specific gravity or purity of the mercury or as to cistern level or capillarity, and without such fears as that the scale of the mercury column was not properly graduated. I have had one of these in practical use for several months and am greatly pleased with its performance, and would recommend one of them as a part of the outfit of any expert who conducts an important engine test.

Mr. Thomson.—Regarding the suggestion of Professor Webb to infer the quantity of discharge, first, by measuring the reaction of the nozzle; or, second, by measuring the velocity of the flow in a tube, I would suggest that either of these schemes would involve the same difficulty which Mr. Freeman and myself have attempted to obviate, in that the discharge of the nozzle being variable in its rate it would therefore become necessary to provide means whereby to record the extent and duration of the variation in the reactions of the nozzle, or the changes and the duration thereof in the velocity of flow. I do not pretend to say that this might not be satisfactorily accomplished, but I am of the opinion that either of these plans present quite as grave difficulties and would probably be open to the same criticisms as those already presented.

In fine, the fundamental principle here involved is precisely the same in each and all of the several modifications, and may be briefly presented as follows: 1st. It is proposed to measure the volume of water discharged from the nozzle. 2d. The mode of ascertaining the volume is not by measurement of the whole, but by inference. 3d. The rate of discharge from the nozzle is not constant, but variable.

Now, the means suggested for performing the functions of inference are: 1st. By Mr. Freeman, a gauge capable of indicating (but not recording) the changes of pressure due to the variation in rate of discharge. 2d. By the writer, a meter adapted to actually measure and record a portion of the total discharge. 3d. By Professor Webb, means (not specified) for measuring and recording the extent and duration of the reactions of the nozzle, due to changes in the velocity of flow. 4th. Also by Professor Webb, means (not specified) for constantly measuring and recording the variable velocity of flow in a tube.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

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(Vol. XXIV.—June, 1891.)

THE FALSE ELLIPSE REDUCED BY EQUATIONS OF CONDITION.

By ARTHUR S. C. WÜRTELE, M. Am. Soc. C. E.

Elliptical curves are often used in engineering structures, but from the mechanical difficulties in striking such curves, they are generally replaced by curves struck with arcs of circles from two or more radii at different centers, according to formulas given in engineering works generally limited to 3 and 5 center curves, beyond which there are few rules or instructions how to proceed.

In true elliptical curves the radii vary constantly, according to certain laws, and the curve may be represented by the general equation of condition $a^2 y^2 + b^2 x^2 = r^2 b^2$, from which all the properties of the curve may be deduced. Curves struck with radii, varying only at fixed points, cannot be so simply represented, though equations of condition can be found by means of which a curve of any number of centers may be struck. The best curve described with arcs of circles, will be the one most nearly approaching to a true ellipse. Now the curvature of an ellipse at any point, is the radius of the osculatory circle at that point; and the osculatory circle, is that which has contact of the second order, with an ellipse, or of which the first and second differential co-efficients

of circle and ellipse equations, are equal. The differential equation for radius of osculatory circle is $R^2 = \dfrac{\left\{1 + \left(\dfrac{d\,y}{d\,x}\right)^2\right\}^3}{\left(\dfrac{d^2\,y}{d\,x^2}\right)^2}$ which gives for maximum and minimum radii of ellipse at ends of diameters;—$r_{max} = \dfrac{a^2}{b}$, and $r_{min} = \dfrac{b^2}{a}$, which should be the limiting radii of first and last curve in a multicenter curve: that is, the longest radius should not exceed $\dfrac{a^2}{b}$, and the shortest radius should not be less than $\dfrac{b^2}{a}$, in a curve approximating to a true ellipse.

The general equations of condition for a curve of any number of centers, may be stated as follows for one quadrant:

Let r_1 r_{11} r_{111} .... r_n be the radii, commencing with the greatest.

" A_1 A_{11} A_{111} .... A_n be the angles used with radii.

" d_1 d_{11} d_{111} .... d_{n-1} be the differences of radii.

" a = half span, b = rise.

The following general equations must be fulfilled:

I. d_1 (sin. A_1 + cos. A_1) + d_{11} [sin. ($A_1 + A_{11}$) + cos. ($A_1 + A_{11}$)] .... + d_{n-1} [sin ($A_1 + A_{11}$ ....+ A_{n-1}) + cos. ($A_1 + A_{11}$ .... + A_{n-1})] — ($d_1 + d_{11}$ + ... d_{n-1}) = $a - b$.

II. d_1 cos. A_1 + d_{11} cos. ($A_1 + A_{11}$) + ... d_{n-1} cos. ($A_1 + A_{11}$ + .. A_{n-1}) + $b = r_1$.

III. d_1 sin. A_1 + d_{11} sin ($A_1 + A_{11}$) + ... d_{n-1} sin. ($A_1 + A_{11}$ + .. A_{n-1}) — a = — r_n.

Now, by assuming, in the first place, the angles varying as may be desired, and filling in equation I, d will be obtained (either directly or varying in any given ratio, by substituting ρd for d_{11} and so on), so long as the equations of condition are fulfilled and result in positive numbers. Then d from equation I is replaced in equations II and III, and longest and shortest radii are obtained.

Example.

1. Let $a = 50$, $b = 30$.

Required an arch of seven centers (four arcs in each quadrant) with differences of radii equal, and angles $A_1 = 25°$, $A_{11} = 25°$, $A_{111} = 20°$, $A_{1111} = 20°$, $d_1 = d_{11} = d_{111}$.

$$\text{From I. } d = (a-b) \div \left\{ \begin{array}{l} \sin.\ A_{\text{I}} + \sin.\ (A_{\text{I}} + A_{\text{II}}) + \sin.\ (A_{\text{I}} + \\ \quad A_{\text{II}} + A_{\text{III}}) + \cos.\ A_{\text{I}} + \cos.\ (A_{\text{I}} + \\ \quad A_{\text{II}}) + \cos.\ (A_{\text{I}} + A_{\text{II}} + A_{\text{III}}) - 3 \ldots \end{array} \right\} = 19.61$$

$$\text{From II. } r_{\text{I}} = b + d\ [\cos.\ A_{\text{I}} + (\cos.\ A_{\text{I}} + A_{\text{II}}) + \cos.\ (A_{\text{I}} + A_{\text{II}} + A_{\text{III}})] \ldots\ldots = 67.08$$

$$\text{From III. } r_{\text{IV}} = a - d\ [\sin.\ A_{\text{I}} + \sin.\ (A_{\text{I}} + A_{\text{II}}) + \sin.\ (A_{\text{I}} + A_{\text{II}} + A_{\text{III}})] \ldots\ldots = 8.26$$

These results, being all positive, show the curve to be possible, and can be constructed as below:

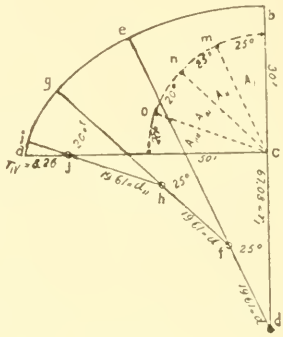

Fig. 1.

General Process of Construction.

Construct rise bc at right angles to half span ac, and produce to d, making bd equal to longest radius R; set off the given angles by lines cm, cn, co, from center, draw de parallel to cm; set off df equal to d; draw fg parallel to cn; set off fh equal to d, and so on, and if construction is correct ja will be equal to r_{IV}.

2. Taking the same example and introducing the condition that the differences of radii vary in geometrical ratio we have

$$a = 50,\ b = 30,\ A_{\text{I}} = 25°,\ A_{\text{II}} = 25°,\ A_{\text{III}} = 20°,\ A_{\text{IV}} = 20°.$$

$$d_{\text{II}} = \rho d_{\text{I}},\ d_{\text{III}} = \rho^2 d. \quad \text{Let } \rho = 0.5.$$

$$\text{From I. } d_{\text{I}} = (a-b) \div \left\{ \begin{array}{l} \sin A_{\text{I}} + \cos.\ A_{\text{I}} + \rho\ [\sin.\ (A_{\text{I}} + A_{\text{II}}) + \\ \quad \cos.\ (A_{\text{I}} + A_{\text{II}})] + \rho^2\ [\sin.\ (A_{\text{I}} + A_{\text{II}} \\ \quad + A_{\text{III}}) + \cos.\ (A_{\text{I}} + A_{\text{II}} + A_{\text{III}})] - \\ \quad (1 + \rho + \rho^2) \ldots\ldots \end{array} \right\} = 33.13$$

$$d_{\text{II}} = d_{\text{I}} \times \rho \ldots\ldots = 16.56$$

$$d_{\text{III}} = d_{\text{I}} \times \rho^2 \ldots\ldots = 8.28$$

From II. $r_1 = d\,[\cos. A_1 + \rho \cos. (A_1 + A_{11}) + \rho^2 \cos. (A^1 + A_{11} + A_{111})] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots = 73.50$

From III. $r_{IV} = d\,[\sin. A_1 + \rho \sin. (A_1 + A_{11}) + \rho^2 \sin. (A_1 + A_{11} + A_{111})] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots = 15.53$

These results, being all positive, show the curve to be possible, and it can be constructed as below:

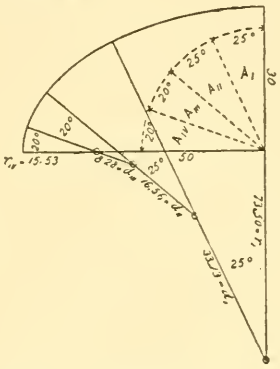

Fig. 2.

3. For three center curves the equations of condition reduce to a simple form:

From I. $\ldots\ldots\ldots\ldots\ldots\ldots d = \dfrac{a - b}{\sin. A_1 + \cos. A_1 - 1}$

From II. $\ldots\ldots\ldots\ldots\ldots\ldots r_1 = d \cos. A_1 + b$

From III. $\ldots\ldots\ldots\ldots\ldots\ldots r_2 = a - d\,(\sin A_1)$.

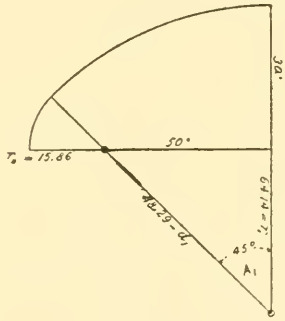

Fig. 3.

From which by substitution of d:

$$r_1 = \frac{a \cos. A_1 + b\,(\sin. A_1 - 1)}{\sin. A_1 + \cos. A_1 - 1}$$

$$r_{11} = \frac{b \sin. A_1 + a\,(\cos. A_1 - 1)}{\sin. A_1 + \cos. A_1 - 1}, \text{ and when } \frac{r_1}{r_{11}} \text{ is called } \rho$$

$$\rho = \frac{r_1}{r_{11}} = \frac{a \cos. A_1 + b \sin. A_1 - b}{a \cos. A_1 + b \sin. A_1 - a}$$

EXAMPLE.

Let $a = 50'$, $b = 30'$, $A_1 = 45°$.

From I ..... $d = \dfrac{a - b}{2 \sin. A_1 - 1} = 48.29$

From II ..... $r_1 = b + d \cos. A_1 = 64.14$

From III ..... $r_{11} = a - d \sin. A^1 = 15.86$

which may be constructed as Fig. 3.

4. Considering the ratio between the radii

$\rho = \dfrac{r_1}{r_{11}} = \dfrac{a \cos. A_1 + b \sin. A_1 - b}{a \cos. A_1 + b \cos. A_1 - a}$, and taking $b = ya$, we have $\rho = \dfrac{\cos. A_1 + y \sin. A_1 - y}{\cos. A_1 + y \sin. A_1 - 1}$, from which by inspection and differentiation,* it is found that ρ will be a minimum when $y = \tan. A_1$. It will become infinite when $\cos. A_1 + y \sin. A_1 = 1$, or $y = \cos. A_1$, because the denominator then becomes 1 — 1 or 0. The second radius then becomes 0. Since to have ρ infinite in equation, $\rho = \dfrac{r_1}{r_{11}}$, r_{11} must reduce to 0. In this latter case, the curve becomes a circular segment, and A_1 a maximum.

Let y=0.9, then ρ is a min. when $A_1 = 41°59'$ and a max. when A_1 is 83°58′

.8,	"	"	38.40	"	"	77.20
.7,	"	"	35.00	"	"	70.00
.6,	"	"	30.58	"	"	61.56
.5,	"	"	26.34	"	"	53.08
.4,	"	"	21.48	"	"	43.36
.3,	"	"	16.42	"	"	33.24
.2,	"	"	11.19	"	"	22.38
.1,	"	"	5.43	"	"	11.26

The most regular three-center curve is formed with ρ a minimum.

Let $a = 50$, $b = 30$, y is 0.6 and A is 30° 58′ by equations for three-

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* Differential co-efficient of $\rho = \dfrac{\cos. A_1 + y \sin. A_1 - y}{\cos. A_1 + y \sin. A_1 - 1}$

$$\frac{d\rho}{dA} = \frac{(\cos. A + y \sin. A - 1)(-\sin. A + y \cos. A)^1 - (\cos A_1 + y \sin. A_1 - y)(-\sin. A_1 + \cos. A)}{(\cos. A_1 + y \sin. A_1 - 1)^2}$$

made equal to 0 for minimum, denominator cancels out and numerator is reduced by factoring:

$$(y - 1)(-\sin. A_1 + y \cos. A_1) = 0$$

Therefore

$$-\sin. A_1 + y \cos. A_1 = 0$$

$$y \cos. A_1 = \sin. A_1$$

$$y = \frac{\sin. A_1}{\cos. A_1} = \tan. A_1 \text{ where } \rho \text{ is a minimum.}$$

center curve. Then $d = 53.76$, $r_1 = 76.10$, $r_{11} = 22.30$. The curve may be constructed as follows:

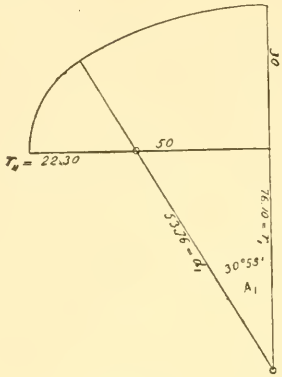

Fig. 4.

6. For a five-center curve the equations of condition may be reduced as follows:

I. d_1 (sin. A_1 + cos. A_1) + d_{11} [sin. ($A_1 + A_{11}$) + cos. ($A_1 + A_{11}$)] $-(d_1 + d_{11}) = a - b$.

II. d_1 cos. $A_1 + d_{11}$ cos. $(A_1 + A_{11}) + b = r_1$.

III. d_1 sin. $A_1 + d_{11}$ sin. $(A_1 + A_{11}) - u = r_{111}$.

d_1 will have some ratio to d_{11}. Let $d_{11} = \rho d_1$.

Then $d_1 = (a - b) \div \begin{cases} \text{sin. } A_1 + \text{cos. } A_1 - 1 + \rho \text{ [sin. } (A_1 + A_{11}) + \\ \text{cos. } (A_1 + A_{11}) - 1]. \end{cases}$

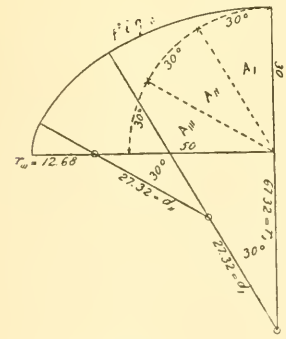

Fig. 5.

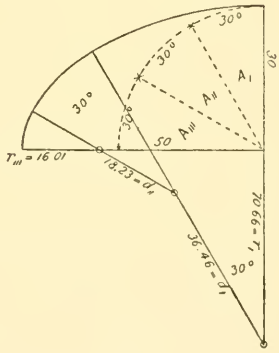

Fig. 6.

$r_1 = d$ [cos. $A_1 + \rho$ cos. $(A_1 + A_{11})$] $+ b$.

$r_{111} = a - d$ [sin. $A_1 + \rho$ sin. $(A_1 + A_{11})$].

Let $a = 50$, $b = 30$. $A_1 = A_{11} = A_{111} = 30°$, and let $\rho = 1$.

From which $d = 27.32$, $r_{\text{I}} = 67.32$, $r_{\text{III}} = 12.68$.

Let $\rho = 0.5$. Then $d = 36.46$, $d_{\text{II}} = 18.23$, $r_{\text{I}} = 70.66$, $r_{\text{III}} = 16.01$.

Special Constructions.

Given AC half span and BC rise at right angles.—Three-centered curves.

Construction No. 1. Let $r = \dfrac{BC^2}{AC}$ = least radius AG.

Take $CD = CB$, draw AB.

Make DE parallel to AB.

Take $BF = CE$.

Take $AG = CE$. Draw GF.

Draw IH perpendicular to GF bisected in I.

Then H and G are centers required.

With radius HB at center H draw arc BJ, then with radius GJ at center G, draw arc JA, completing the half curve.

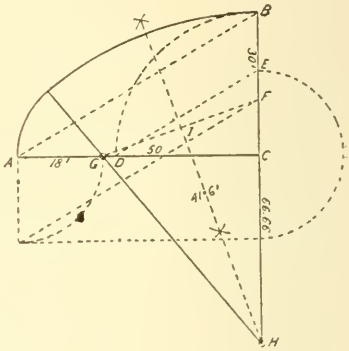

Fig. 7.

Construction No. 2. From Mahan. Take $\dfrac{R}{r}$ minimum.

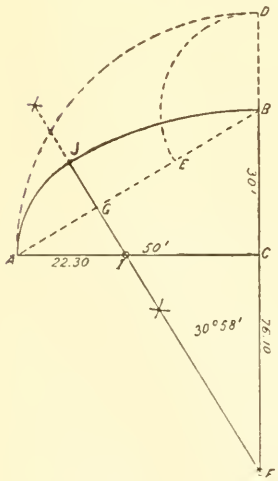

Fig. 8.

Take $CD = CA$. Draw AB and describe arc AD from center C.

Take $BE = BD$. Draw GF perpendicular to AE bisected in G, cutting AC in I, then F and I are centers required.

Draw the curve as before.

Construction No. 3. By Mahan. Let the angles at H and G be 60° and 30°.

Take $CD = CA$. Draw quadrant, DEA.
Take $AE = AC$. Draw DE.
Draw BF parallel to DE. Draw CE.
Draw FG parallel to EC, cutting AC in H and BC in G.
Then G and H are centers required.
Draw the curve as before.

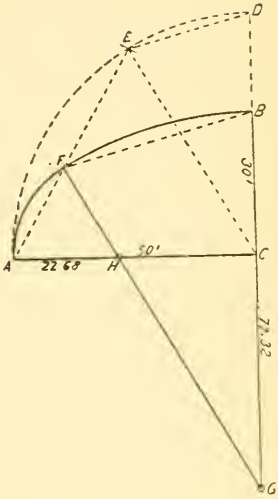

Fig. 9.

Construction No. 4. By Würtele. Let the angles at H and I be 60° and 30°.

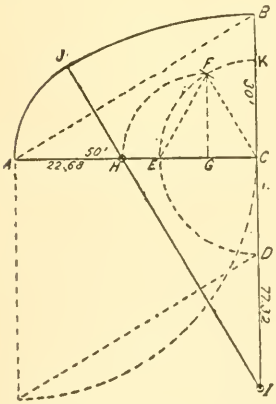

Fig. 10.

Take $BD = AC$.
Take $CE = CD$. Draw quadrant EFK.
Take $EF = CE$. Draw FC.
Draw FG parallel to BC.
Take $GH = GF$.
Draw HI parallel to FC and produce to J, cutting BC in I.
Then I and H are centers required.
Draw the curve as before.

Construction No. 5. From Haskell. Take angles at L and H at 60° and 30°.

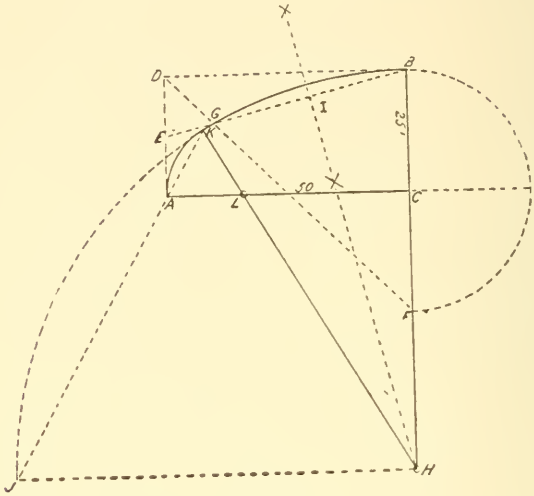

Fig. 11.

Take $BD = CA$ and parallel to CA. Take $AD = CB$ and parallel to CB. Take $DE = EA$. Draw EGB. Take $CF = CB$. Draw FD. FD cu's BE in G. Draw HI perpendicular to GB bisected in I. Draw $HJ = HB$ parallel to CA. Draw quadrant $BGKJ$. Draw JA cutting arc BG in K. Draw HK cutting AC in L. Then H and L are centers required. Draw the curve as before.

Construction No. 6. By Würtele. Let the angles be 45°.

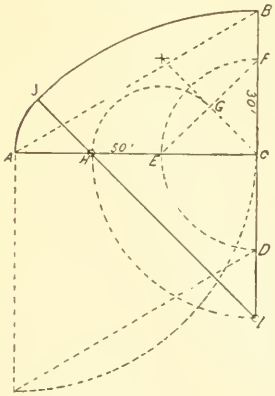

Fig. 12.

Take $BD = AC$.

Take CE and $CF = CD$. Draw EF.

Draw CG perpendicular to EF, cutting EF in G.

Take $EH = EG$.

Take $CI = CH$. Draw IHJ.

Then I and H are centers required.

Draw the curve as before.

Construction No. 7. General construction.

Take $AD = BE$, less than BC and strike curve AH. Draw DE.

Draw FG perpendicular to DE, bisected in G.

Draw FD to H.

FD are centers required.

Draw the curve as before.

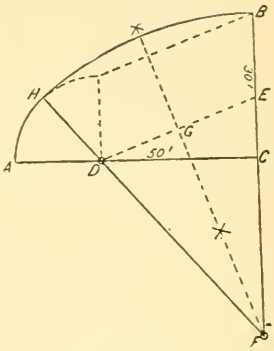

Fig. 13.

Construction No. 8. From Nystrom. Let the angles be 30° and 60°.

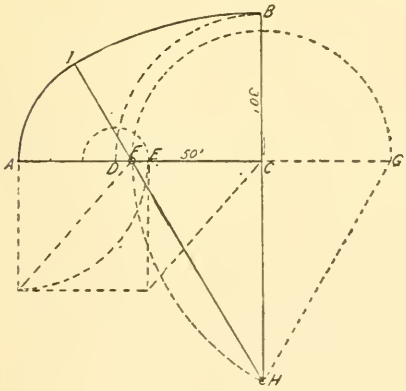

Fig. 14.

Take $CD = CB$.

Take $DE = \frac{1}{3} AD$.

Take $CF = AE$.

Take $CG = CF$.

From G as a center, with radius GF, strike an arc, cutting BC, produced in H.

Draw HF to I.

Then H and F are centers required.

Draw the curves as before.

Construction No. 9. Old construction.

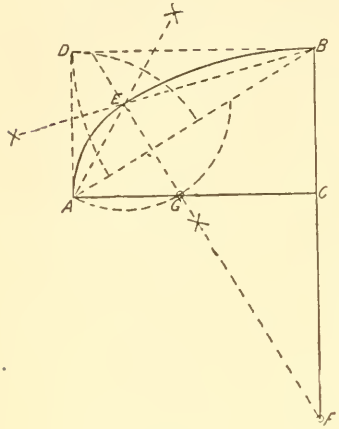

Fig. 15.

Draw BD parallel and equal to CA. Draw AB.

Draw $AD = CB$.

Draw BE, bisecting angle ABD.

Draw AE, bisecting angle BAD.

BE cuts AE in E.

Draw EF perpendicular to AB, cutting AC in G.

Then F and G are centers required.

Draw the curves as before.

Five-centered Curves.

Construction No. 1. By Würtele. Let the angles be 30°.

Take $CF = CA$ on CB produced.

Draw quadrant FA.

Take $AG = CA$.

Draw CD and $BD = CB$.

Draw GC, bisecting DB in E.

Take $BH = BF$.

Draw HI parallel to CA.

Take $HI = HB$.

Draw IJ parallel to GC, cutting AC in K.

Make $AL = LK$.

Take $JM = LK$.

Draw MN parallel to CG.

Draw OL parallel to DC, cutting MN in P.

MPL are centers required.

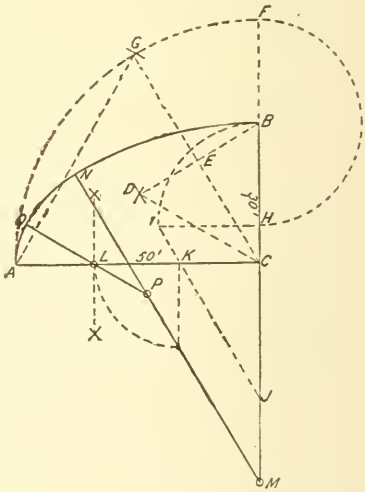

Fig. 16.

With radius MB at center M, draw arc BN. With radius PN at center P, draw arc NO. With radius LO at center L, draw arc OA.

Construction No. 2. From Johnson.

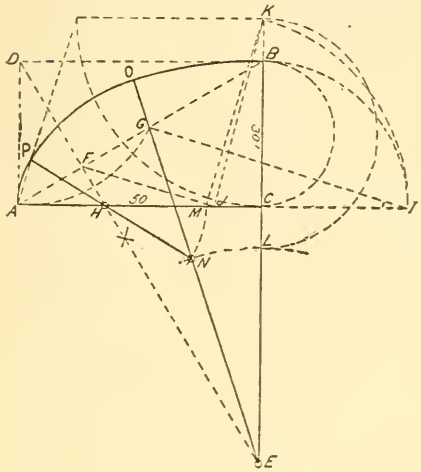

Fig. 17.

Draw BD parallel to and $=$ CA.

Draw $AD = CB$. Draw BA.

Drop DE perpendicular to AB, cutting AC in H; cutting AB in F; cutting BC, produced in E.

Take $EG = AF$.

Take $CI = CB$ on AC produced. Draw GI.

Draw FJ parallel to GI.

Make $JK = JI$, cutting CB produced in K.

Take $CL = KB$.

Take $AM = KC$.

Strike arc LN from centre E. Strike arc MN from center H. Draw ENO and NHP. ENH are centers required. Draw the curves as in the last figure.

Construction No. 3. From Vose.

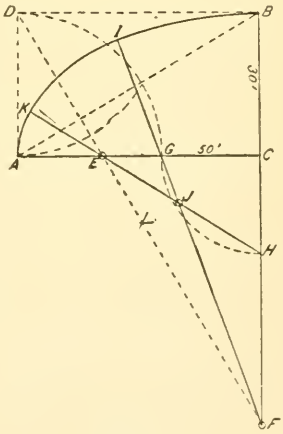

Fig. 18.

Draw BD parallel to and $=$ CA.

Draw AD parallel to and $=$ CB. Draw AB.

Draw DF perpendicular to AB, cutting AC in E and BC in F.

Take $AG = AD$.

Take $CH = CG$.

Draw FG produced to I.

Draw HE produced to K, cutting FG in J.

FJE are centers required.

Draw the curve as before.

Construction No. 4. From Shaw.

Let $R = \frac{AC^2}{BC}$. Let $R_1 = \frac{BC^2}{AC}$.

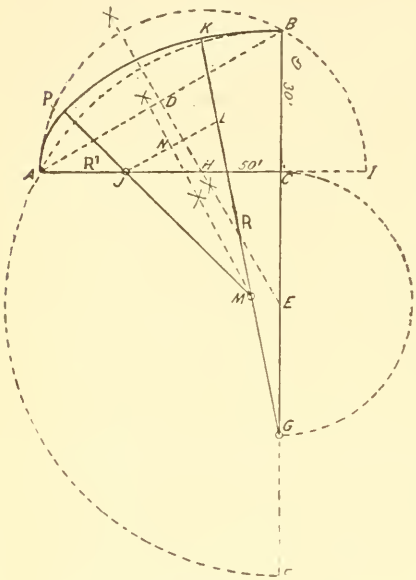

Fig. 19.

Draw AB.

Draw DE perpendicular to AB, and bisecting it in D and cutting BC in E and AC in H.

Take $EF = EB$ on BC produced.

Take $FG = BC$.

Take $HI = AH$ on AC produced.

Take $AJ = CI$.

Draw $GK = GB$ at any angle with GB.

Take $KL = AJ$. Draw JL.

Draw MN perpendicular to JL bisected in N, cutting GK in M.

Draw MJP.

GMJ are centers required.

Draw the curves as before.

Construction No. 5. From Mahan.

Take $BE = AD$ less than BE.

Draw DE.

Draw FG perpendicular to DE, bisected in F, cutting BC in G.

Bisect GE in H.

On center D with radius $DI = EH$. Draw arc IJ.

Take point J on arc IJ so that LM cuts DC.

Draw HJ.

Draw KL perpendicular to HJ, bisected in K.

Draw LJM. Draw JDN. LJD are centers required. Draw curve as before.

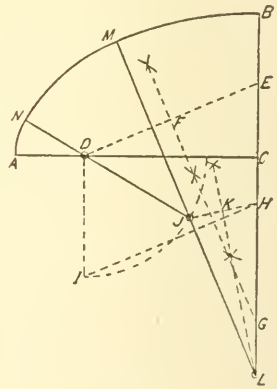

Fig. 20.

In above constructions many more lines are shown than are necessary, so as to indicate a continuous geometrical system starting from given

quantities and working only with parallel ruler and bow pen. Special constructions are obtained by reducing equations and plotting them geometrically, in which manner several of those given above were obtained.

Construction No. 6. From points on ellipse.

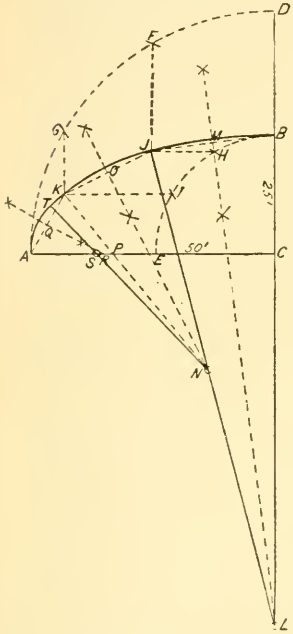

Fig. 21.

Draw quadrant AD to radius CA.

Trisect quadrant in FG.

Draw quadrant BE to radius CB.

Trisect quadrant in HI.

Draw FJ and GK parallel to BC.

Draw HJ and IK parallel to AC, thus obtaining points J and K.

Draw ML perpendicular to BJ, bisected in M.

Draw ON perpendicular to JK, bisected in O.

Draw LJ.

Draw NK, cutting AC in P.

Draw QR perpendicular to AK, bisected in Q, cutting AC in R.

Take $RS = \frac{1}{4} RP$.

Draw NST.

LNS are centers required.

Draw curve as before.

J and K are points on ellipse, and a multicenter curve is constructed by dividing quadrants into as many parts as required and proceeding as above.

When BC is over $\frac{2}{3} AC$ then S coincides with P.

Oval Curves.

Case 1.

Given greatest diameter.

Least radius $\frac{1}{3}$ diameter, and greatest radius $\frac{2}{3}$ diameter.

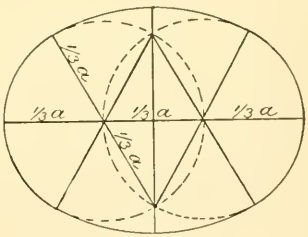

Fig. 22.

Case 2.
Given greatest diameter.
Least radius $\frac{1}{4}$ diameter.
Greatest radius $\frac{3}{4}$ diameter.

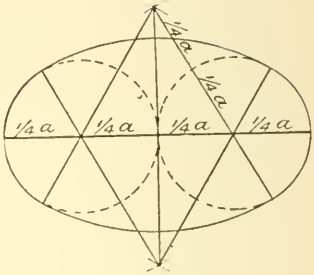

Fig. 23.

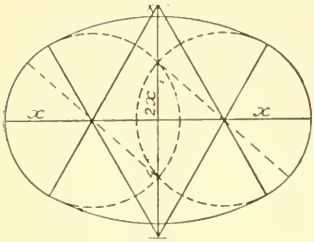

Fig. 24.

Case 3.
Given greatest diameter.
Least radius greater than $\frac{1}{4}$ diameter.

Egg-shaped Curves.

Case 1.
Given diameter and height.
Let $d = 0.77\ h$.
Radii $\frac{1}{2}\ d$, d and $\frac{3}{10}\ d$.

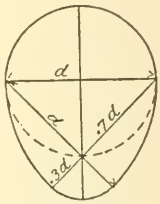

Fig. 25.

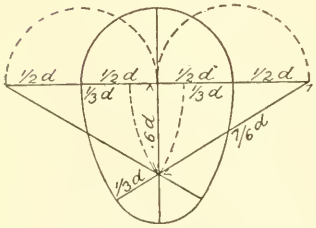

Fig. 26.

Case 2 Old sewers.
Let $d = \frac{7}{10}\ h$.
Radii $\frac{1}{2}\ d$, $\frac{3}{2} d$ and $\frac{1}{3}\ d$.

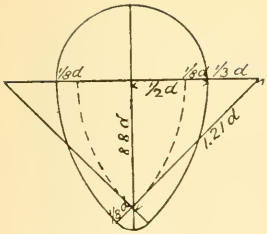

Fig. 27.

Case 3. Approved for sewers. Ency. Britt.

Let $d = \frac{2}{3} h$.

Radii $\frac{1}{2} d$, $\frac{4}{3} d$ and $\frac{1}{8} d$.

Case 4. From Molesworth.

Let $d = \frac{2}{3} h$.

Radii $\frac{1}{2} d$, $\frac{3}{2} d$ and $\frac{1}{4} d$, or $\frac{1}{3} h$, h and $\frac{1}{6} h$.

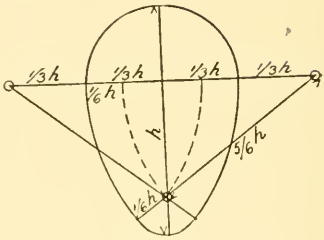

Fig. 28.

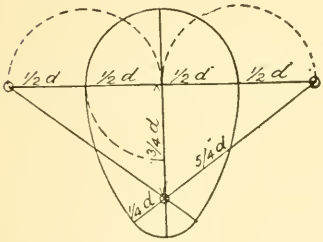

Fig. 29.

Case 5. From Merriman and Ency. Britt.

Let $d = \frac{2}{3} h$.

Radii $\frac{1}{2} d$, $\frac{3}{2} d$ and $\frac{1}{4} d$.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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(Vol. XXIV.—June, 1891.)

NOTES ON A MOUNTAIN SLIDE.

By W. G. CURTIS, M. Am. Soc. C. E.

WITH DISCUSSION.

Land slips along railway lines are of such frequent occurrence and the methods employed for their quick removal are usually so simple and stand so completely within the category of commonplace experiences in railroad management, that, as a general rule, papers relating to such obstructions can possess little, if any, professional value. A mountain slide which obstructed one of the lines operated by the Southern Pacific Company in northern California last winter, occurred under rather unusual conditions; therefore a description of it and of the means employed to clear it away from the track may be of some interest. As indicated by appended topographical sketch, Fig. 1, tunnel No. 9 which is 670 feet long, is pierced through a spur on the easterly side of the Sacramento River cañon, and is approached from the north through 200 feet of "side hill" excavation in material which may be described as shaly talcose rock, with greatest depth of cut on center line ranging from 26

to 45 feet, and at the top of the slope on the mountain side something over 120 feet, the slope of cut averaging a little less than ½ to 1. Last season's rain-fall in this region was quite phenomenal, amounting to over 100 inches precipitation (rain and melted snow) for the five months ending March 1st, 1890, as against 59 inches average annual rainfall. As a consequence the ground was heavily saturated, and large masses of earth and slaty rock slid down from the mountain slope and fell upon the track, over the edge of a comparatively solid rock ledge which remained in place undisturbed by the slide above it, to a height of a little more than 100 feet above the railroad grade.

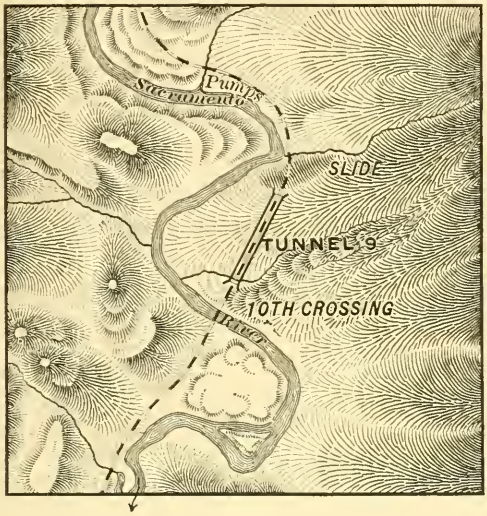

FIG. 1.

Plate No. LXIII gives a general view of the locality, and Fig. 2 is a reduced longitudinal profile; the length of slide measured along the track is about 200 feet, the height of rock slope is about 100 feet, and the vertical height from grade to top of slide about 300 feet. Roughly estimated, the total quantity of material

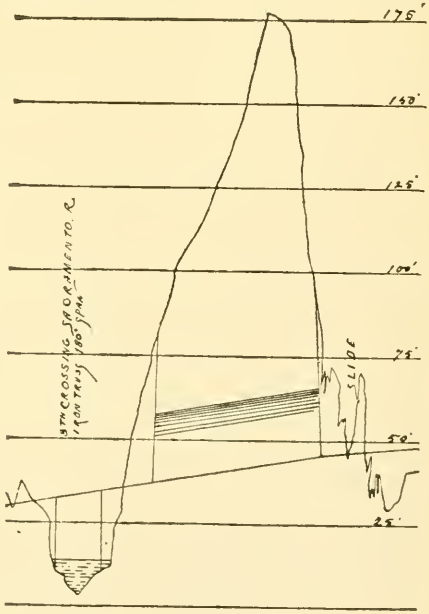

FIG. 2.

which, from first to last, fell upon the roadbed was 25 000 cubic yards. A road for team transfer of passengers, freight, etc., was immediately graded around tunnel No. 9 spur, and the work at the slide covered with all the men that could be handled, in day and night shifts. The weather being favorable, rapid progress was made, and when the track had been almost cleared with an expenditure of labor footing up 5 500 days work (the work of one man for eleven hours being taken as one day's work), a heavy storm of alternating rain and snow set in, the slide was again started and its movement continued until the pile resting upon the track had been restored to its original dimensions. Up to this time no serious difficulty had been experienced in working with carts and wheelbarrows all the men that could be placed upon the limited space occupied by the obstruction, but at this time the material around the edges of the slide had become so much softened up, that small or large masses of earth and rock were constantly dumping over the rock ledge and falling upon the workmen below, alarming them to such an extent that night-work became impracticable, and the day men were soon so much endangered that under observance of all necessary precautions for their safety, very little effective work could be done.

At this juncture we decided to clear the track with appliances similar to those employed in hydraulic mining operations, which had been previously used for railroad work in the Sierra Nevada mountains. The regulation gravity head of water for this purpose could not, however, be quickly obtained, and the pumping plant illustrated in Plate LXIII was hastily designed to utilize machinery and materials already in our hands, or which could at once be obtained and made serviceable for other uses afterwards. Locomotives to supply steam were sent to the north end of the tunnel, and the other appliances delivered on cars at the south end and hauled on wagons and improvised sleds or stone boats from the south end of the tunnel to the nearest ground available for assembling the entire plant. The hydraulic stream was turned on the work, in forty-three hours from the time the first shipment of materials arrived at the south end of the tunnel, the snow falling heavily nearly all of this time.

Twelve ordinary standard "surface" steam pumps, with capacities ranging from 150 to 500 gallons of water discharged per minute at ordinary speed, and aggregating for the gang of pumps about 3 300 gallons discharging capacity per minute, were placed end to end on a bed-

frame 32 inches wide and 128 feet long, constructed with railroad ties and trestle stringer timber. The line of pumps was set about 100 feet from the river bank and about 15 feet above the surface of the water in the river. All of the pumps were connected to a 12-inch, lap-welded pipe, and a suction pipe was laid from each pump to the river. The southerly end of the 12-inch discharge pipe was connected to a circular air chamber, 60 inches in diameter and 96 inches high, which served admirably to equalize the fluctuations of the pumps, giving the stream practically the same steadiness as the ordinary gravity pressure jet of the hydraulic miners. From the air chamber to the face of the work, water was conducted through pipe made of No. 12 Birmingham gauge, sheet iron, and riveted up in the shop into sections 30 feet long, one end of each section being flared out and the other having its diameter slightly reduced. The pipe was connected up on the ground by inserting the small end of one section of pipe into the larger end of another and driving it in to a snug fit, or making, in mining parlance, a tight "stove-pipe joint." A standard hydraulic giant butt was used, part of the time with a 4-inch discharge nozzle, and at other times with a 3-inch nozzle, according to nature of the material to be washed. The material was washed down on a flat place bordering the river. The method of working is quite plainly shown by Plate No. LXIV; the upper end of the flume and "head dams" being merely planks set on edge to guide the water-borne material or tailings into the flume conducting it away from the work. A small force of men were kept at work to break up, with sledges or by the use of powder, the larger pieces of rock and masses of snow and earth frozen together, and to otherwise expedite the work.

The quantity of material removed by the water jet for nine days (the time taken to open the line), aided by the laborers as above, may be estimated at 9 000 cubic yards, equal to, say, an even 1 000 cubic yards moved each twenty-four hours. Allowing for the time shut down, pumps cut out for repairs, etc., the average discharge of the water jet, under a pressure of 45 to 50 pounds per square inch, may be set down at 2 000 gallons per minute or 200 miner's inches a day. Each miner's inch moved 5 cubic yards each twenty-four hours, a somewhat higher duty than is ordinarily shown in hydraulic mining operations, but this might fairly be expected in handling material previously loosened up, as in the present case.

The average cost per day (twenty-four hours) of operating the hydraulic plant is closely estimated, as follows:

Wood, 25 cords	$75 00
Eight firemen and pumpers	20 00
Machinists and pump repairers	25 00
Men operating hydraulic jet (experts, paid high rates)	30 00
Thirty laborers	50 00
Total	$200 00

or, 20 cents per cubic yard.

Since the track was cleared, protection work (indicated by the appended cross-section plan, see Fig. 3) in the form of shedding, was

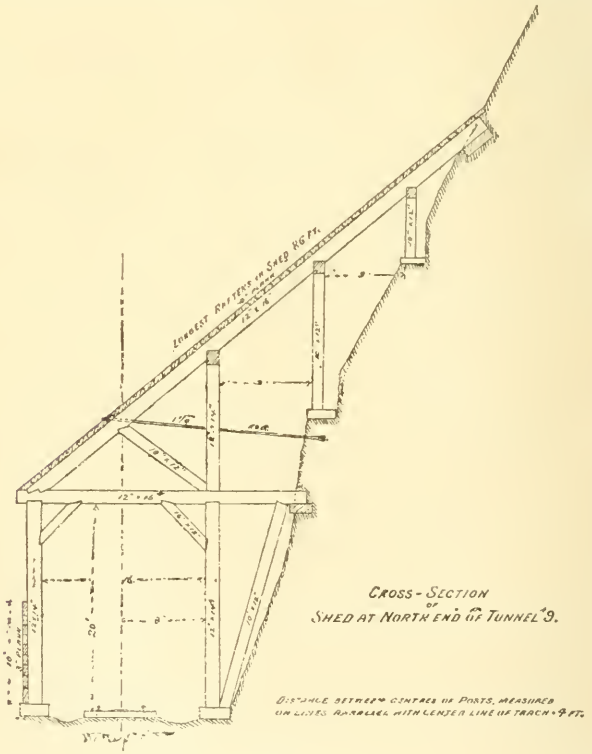

Fig. 3.

extended northward from the tunnel portal about 100 feet. This structure has proved to be sufficiently strong to divert earth and rock which since its construction has fallen down from the slide.

PLATE LXIII.
TRANS. AM. SOC. C. E.
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CURTIS ON MOUNTAIN SLIDE.

PLATE LXIV.
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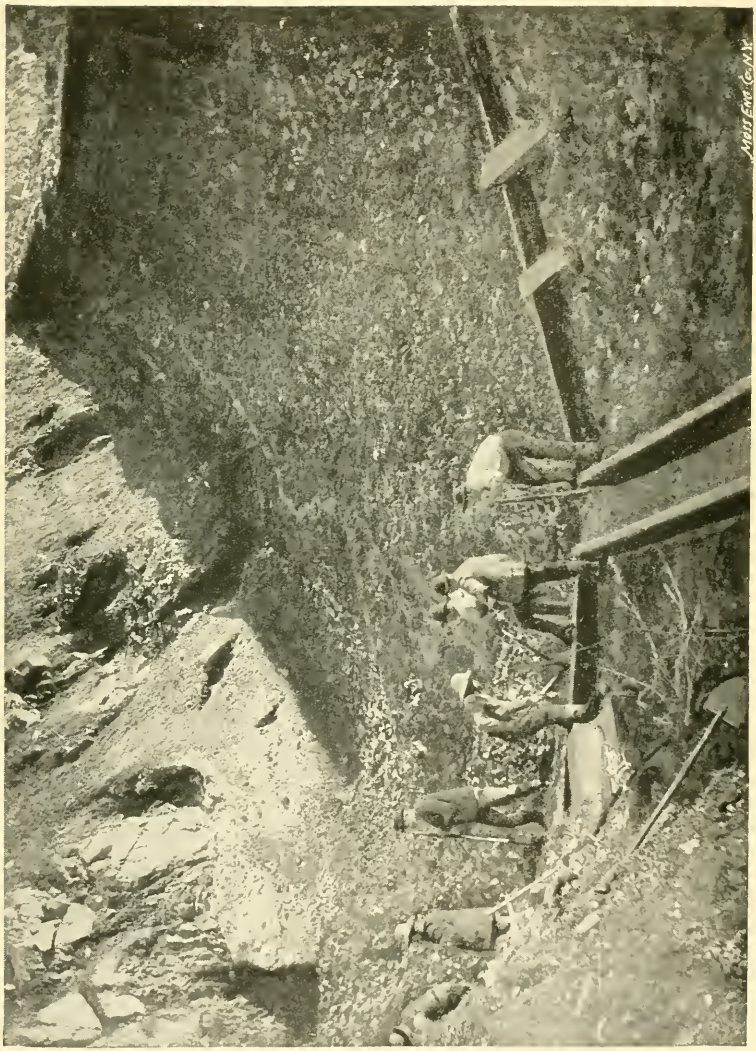
CURTIS ON MOUNTAIN SLIDE.



The appearance of the pile of material covering the roadbed near the completion of the work is quite clearly indicated by the Plates. The top of this pile of material, as it originally came down, was 12 or 15 feet above the top of the tunnel arching, filling the northerly 200 feet of the tunnel with earth to an average depth of about 10 feet. As soon as a "bench" had been taken out with wheelbarrows, low enough down to open an air hole into the tunnel, the removal of earth was carried on within it on cars loaded by the use of wheelbarrows.

DISCUSSION.

William P. Shinn, President Am. Soc. C. E.—The use of the hydraulic jet to get rid of this slide was certainly unique and eminently successful, both as to the speed with which the work was done and as to the cost.

F. Collingwood, M. Am. Soc. C. E.—When preparations were making for sinking the Brooklyn cassion of the East River Bridge I was directed to make some experiments to determine the quantity of sand which could be transported by a jet or small stream of water. The intent was that in case they proved promising the material excavated in the chambers should be carried by this means to the water shafts. The experiments had only progressed far enough to show the practicability of the scheme when it was decided for special reasons to abandon it. In making the experiments a cubical box was made holding a cubic yard, and a trough arranged so that its grade could be readily changed. Water being admitted into the trough, sand was shoveled in at the same time almost as rapidly as the stream would carry it away. It was found that any inclination less than about one in ten left a deposit, and that with that slope, the volume of sand carried was by actual measurement about 50 per cent. of the volume of the water. An experiment was made with a 4-inch siphon pipe, the long leg about 1 foot in excess of the other. This carried the sand faster than two men could possibly shovel it. The tabular results obtained were given in a short paper to the Society in the first volume of the *Transactions*.

Charles B. Brush, Director Am. Soc. C. E.—In water works in the western States, especially along the Missouri River the amount of sediment is very great. In the first settling basins the sediment will amount to a depth of 10 feet in one year. This sediment is removed usually by a water jet from a 2½-inch hose. The drain from the basin is about 2 feet in diameter, if the size is greater the drain is very apt to choke up. If the sediment is allowed to remain in the basins

until the accumulation is 6 or 8 feet deep there is considerable difficulty in removing it with the water jet. On a depth of 2 feet the jet acts with little difficulty, for greater depths the material becomes so compact that the jet will simply make a hole in the silt without removing it. If the basin is cleaned when the silt is not over 2 feet in depth the water jet is very effective. The bottoms of the basins are inclined about one in ten.

Mr. Collingwood.—What proportion of water do they have to use to the amount of silt removed?

Mr. Brush.—I am not definitely informed on that point, the amount depends very much on the depth of the silt.

J. Foster Crowell, M. Am. Soc. C. E.—Is the difference observed due to the difference in quantity or quality?

Mr. Brush.—It is due to quantity, to the weight of the silt that has accumulated. The upper 2 feet are easily removed but further down the silt is very tenacious.

Mr. Crowell.—I have had no experience of my own, but some time ago I investigated the results of a jet operation in Georgia, and found that the quality of the material to be removed had a very important effect in the economy, as might be supposed. With loam and with sandy soils generally the economy was very great, the quantity removed was very much in proportion to the water, but as the clay predominated the economy became less and less, and there are clays which cannot be removed at all by the water jet. I should suppose from the statement of the cost of this particular work of removing the slide, that the material was favorable for the purpose. Mr. Curtis estimates the cost as about twenty cents per yard; of course we must make allowances for the conditions, the difficulty of applying the jet and other reasons; material is often removed for one-tenth of that, where the conditions are very favorable.

Mr. Brush.—In the work on the Hudson River tunnel the use of the water jet was attempted at the depth at which the tunnel is building, 50 feet below the bottom of the river. At that point the water jet had no effect at all, it simply would bore a hole. The water jet on the silt at the surface is very effective; the only way we could use the jet in the Hudson River tunnel was to break up the silt in small pieces and then the water jet would work easily.

P. F. Brendlinger, M. Am. Soc. C. E.—I am sorry the author of the paper is not here, because I would like to know whether he could not have applied a steam shovel to greater economy than a water jet. It may be that he had no steam shovel, which would be a good excuse, but I feel satisfied that a steam shovel would have done the work at at least half the cost. It is pretty difficult to make a contract to take out material with a steam shovel at ten cents a yard, but when the company has a steam shovel they can do it much cheaper. Twenty cents is certainly a very

high price for moving a silt of that nature. A good steam shovel would certainly move more than a thousand yards in twenty-four hours, it ought to move 1 500, the conditions being good and the cars being promptly furnished; time is very frequently an object, and I should say it would have been in this particular case.

J. H. Wallace, M. Am. Soc. C. E.—Being familiar with the work of moving this slide, as described by Mr. Curtis, I will say, in answer to Mr. Brendlinger's query as to whether a steam shovel could not have been used to greater economy than a water-jet, that although the company had a steam shovel which was within reach at the time, still the situation was such that a steam shovel could not be used. The slide was in the mouth of a tunnel, in a very mountainous country, and it would have been a very expensive matter to lay any track on which to place cars to be loaded by the shovel. It would then have been necessary to excavate with the steam shovel a cut wide enough not only for the operation of the steam shovel, but also for a track on which to stand cars while being loaded. As such a track would have abutted against the material of the slide, it would have been necessary to make a switch every time a car was loaded, removing the loaded car and placing an empty one in position. Under these circumstances, a steam shovel could not have handled more than four or five hundred yards a day. Moreover, it was extremely doubtful whether a steam shovel could be kept at work. As noted by Mr. Curtis, after the track had been nearly opened by the use of carts and wheelbarrows, the slide started a second time and continued to move until the track was again completely covered, the material being piled up as high as when the first slide occurred. There was thus the danger that the slide might start again at any time and the shovel be completely buried. There was also danger from the large number of rocks of various sizes which were continually detached from the mountain above and precipitated into the cut. Some of these were large enough to have disabled the shovel, and all of them were large enough to have endangered the lives of the men employed on the shovel. While twenty cents per yard may be considered a high price for removing such material under most circumstances, in the case under discussion the object in view was to get the road open at the earliest possible moment and to accomplish this questions of economy were not considered as carefully as they are when work is being planned.

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